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ISC CLASS XII EXAMINATION PAPER 2026

PHYSICS

PAPER - 1

(THEORY)

Time: 3 Hours **Max. Marks: 70**

General Instructions:

1. You are allowed an additional fifteen minutes for only reading the question paper.
2. You must NOT start writing during reading time.
3. There are twenty questions in this paper. Answer all questions.
4. There are four sections in the paper- A, B, C and D. Internal choices have been provided in two questions each in Sections B, C and D.
5. Section A consists of one question having fourteen subparts of one mark each.
6. While attempting Multiple Choice Questions in Section A, you are required to write only ONE option as the answer.
7. Section B consists of seven questions of two marks each.
8. Section C consists of nine questions of three marks each.
9. Section D consists of three questions of five marks each.
10. The intended marks for questions are given in brackets [ ].
11. A list of useful constants and relations is given at the end of this paper.
12. A simple scientific calculator without a programmable memory may be used for calculations.

SECTION-A (14 Marks)

QUESTION 1.

(A) In questions (i) to (vii) given below, choose the correct alternative (a), (b), (c) or (d).

(i) A fish called an electric eel can generate a voltage up to 800 V. If it can supply a current of 5 mA, the maximum power it can deliver is [1]

(a) 4000W
(b) 400W
(c) 40W
(d) 4W

Ans :

(d) 4W

As we know that,

$$P = V \times I$$
$$= 800\ \text{V} \times 0.005\ \text{A}$$
$$= 4\ \text{W}$$

(ii) A collimated beam of protons is travelling with a constant velocity along X-axis.

There is a current carrying solenoid whose axis is also X-axis. If the beam now enters the solenoid along its axis, it will: [1]

(a) describe a circular path.
(b) get deflected along Z-axis.
(c) get deflected along Y-axis.
(d) continue to travel undeflected

Ans :

(d) continue to travel undeflected

When a collimated beam of protons enters a current-carrying solenoid along its axis, the beam continues to travel undeflected. This is because the magnetic field inside the solenoid is directed along the axis of the solenoid, which is the X-axis in this case. Since the protons are also moving along the X-axis, the angle between the velocity of the protons and the magnetic field is 0°. According to the Lorentz Force, $F = qvB\sin\theta$

Since, $(\sin 0^\circ = 0)$, no force acts on the protons.

Hence, the correct answer is (d) continue to travel undeflected.

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(iii) An electron, a proton, a deuteron and an alpha particle are all accelerated from rest through the same potential difference. Which one will have the maximum de Broglie wavelength? [1]

(a) Proton
(b) Deuteron
(c) Electron
(d) Alpha particle

Ans :

(c) Electron

When a charged particle is accelerated through the same potential difference, it gains kinetic energy equal to qV. The de Broglie wavelength of a particle is given by:

$$\lambda = \frac{h}{\sqrt{2mqV}}$$

Thus, $\lambda \propto \frac{1}{\sqrt{m}}$ (for the same charge and potential).

From this relation, the de Broglie wavelength is inversely proportional to the square root of the mass of the particle (for particles accelerated through the same potential difference). Among an electron, proton, deuteron, and alpha particle, the electron has the smallest mass. Therefore, it will have the maximum de Broglie wavelength. Hence, the correct answer is (c) Electron.

(iv) Magnetic susceptibility (ψ) of a material is found to decrease with the rise in its temperature. The material is [1]

(a) diamagnetic
(b) paramagnetic
(c) ferromagnetic
(d) not magnetic

Ans :

(b) paramagnetic

In paramagnetic materials, magnetic susceptibility decreases as temperature increases according to Curie's law:$\left(x \propto \frac{1}{T}\right)$

As temperature rises, thermal agitation opposes the alignment of magnetic dipoles with the external magnetic field, so susceptibility decreases

(v) When a p-n junction diode is forward-biased [1]

(a) it acts as an insulator and no current flows through it.
(b) it offers a low resistance and a large current flows through it.
(c) it offers a high resistance and a small current flows through it.
(d) the width of depletion region increases.

Ans :

(b) it offers a low resistance and a large current flows through it.

When a p-n junction diode is forward-biased, the positive terminal of the battery is connected to the p-side and the negative terminal is connected to the n-side. This reduces the potential barrier and decreases the width of the depletion region at the junction. As a result, the majority charge carriers can easily cross the junction, allowing a large current to flow through the diode. Therefore, the diode offers very low resistance in forward bias. Hence, the correct answer is (b) it offers a low resistance and a large current flows through it.

(vi) When a biconvex lens of glass of refractive index 1.6 was dipped in a certain transparent liquid, it was found to behave like a plane sheet of glass. So, the refractive index of the liquid is [1]

(a) 1·0
(b) 1·4
(c) 1·5
(d) 1·6

Ans :

(d) 1·6

When a biconvex lens is dipped in a liquid and behaves like a plane sheet of glass, its power becomes zero and it no longer converges or diverges light. This happens when the refractive index of the liquid becomes equal to the refractive index of the lens material. Since the refractive index of the glass lens is 1.6, the refractive index of the liquid must also be 1.6. Therefore, the correct answer is (d) 1.6.

(vii) Given below are two statements marked Assertion and Reason. Read the two statements and choose the correct option~

Assertion : In Young's double slit experiment, the first bright band for blue light is closer to the centre than the first bright band for green light.

Reason : Blue light has a longer wavelength than green light. [1]

(a) Both Assertion and Reason are true and Reason is the correct explanation for Assertion.
(b) Both Assertion and Reason are true but Reason is not the correct explanation for Assertion.
(c) Assertion is true and Reason is false.
(d) Assertion is false and Reason is true.

Ans :

(c) Assertion is true and Reason is false.

In Young's double slit experiment, the fringe width depends on the wavelength of light. Since blue light has a shorter wavelength than green light, the bright fringes formed by blue light appear closer to the central bright fringe than those formed by green light. Therefore, the Assertion is true. However, the Reason is false because blue light

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actually has a shorter wavelength, not a longer wavelength, than green light. Hence, the correct answer is (c) Assertion is true and Reason is false.

(B) Answer the following questions briefly:

(i) Calculate the momentum of a photon having an energy of 4.8×10^{-19} J. [1]

Ans :

Energy $E = 4.8 \times 10^{-19}$ J

Speed of the light $c = 3 \times 10^{8}$ m/s

Momentum of a photon is given by

$$p = \frac{E}{c} = \frac{4.8 \times 10^{-19}}{3 \times 10^{8}}$$

$$= 1.6 \times 10^{-27} \text{ kg ms}^{-1}$$

(ii) What is motional emf? [1]

Ans :

Motional emf is the emf induced in a conductor when it moves through a magnetic field and cuts the magnetic field lines.

(iii) Calculate work done in moving a point charge 'q' through a distance 'd' along perpendicular bisector of an electric dipole, which consists of two-point charges $-Q$ and $+Q$ separated by a distance 'L'. [1]

Ans :

For a point on the perpendicular bisector of an electric dipole, the electric potentials due to charges +Q and −Q are equal in magnitude and opposite in sign. Hence, the net electric potential at every point on the perpendicular bisector is zero.

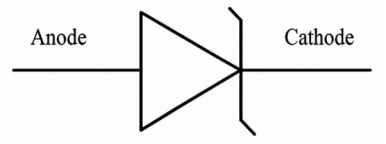
Hence, potential difference (= 0).

$$W = q\Delta V = 0$$

(iv) Draw the symbol of Zener diode. [1]

Ans :

The symbol for a Zener diode is -



(v) A thin convex lens of power 5 D is kept in contact with a thin concave lens of power 8 D. Calculate the focal length of the combination. [1]

Ans :

When two thin lenses are in contact, their powers add up.

For lenses in contact,

$$P = P_1 + P_2$$

$P_1 = +5$ D (convex lens)

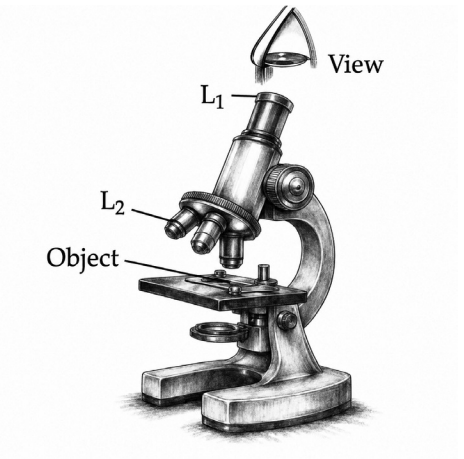
$P_2 = -8$ D (concave lens)

$$P = 5 - 8 = -3 \text{ D}$$

$$f = \frac{1}{P} = \frac{1}{-3} = -0.33 \text{ m}$$

The negative sign indicates that the combination behaves as a concave (diverging) lens.

(vi) The image below shows a compound microscope. Which one of the two lenses L_1 or L_2 has a larger focal length? [1]



Ans :

In a Compound Microscope, the objective lens has a smaller focal length, while the eyepiece (eye lens) has a larger focal length.

Since, (L_1) is the eye lens, it must have the larger focal length, and (L_2) (objective lens) has the smaller focal length.

(vii) Radius of the first Bohr orbit of hydrogen atom is 0.05 nm. Calculate the radius of the third orbit. [1]

Ans :

Given,

$$r_1 = 0.05 \text{ nm}$$

For the Bohr Model of the Atom, the radius of the n^{th} orbit is

$$r_n = n^2 r_1$$

where (r_1) is the radius of the first orbit.

For the third orbit (n = 3)

$$r_3 = 3^2 \times 0.05$$

$$r_3 = 9 \times 0.05 = 0.45 \text{ nm}$$

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SECTION-B (14 Marks)

QUESTION 2.

(i) For point charges Q_1 = +17.7μC, Q_2 = −8.85μC, Q_3 = −17.7μC and Q_4 = 35.4μC are kept as shown in figure 1 below. [2]

Q_4 = 35.4μC

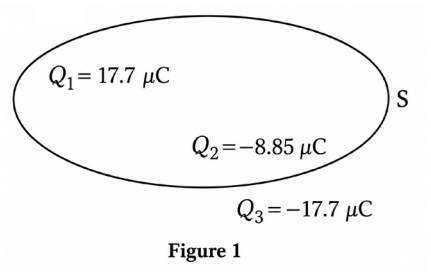

Figure 1

Calculate electric flux emanating from the closed surface S.

Ans :

According to the Gauss's Law

$$\Phi = \frac{Q_{enclosed}}{\varepsilon_0}$$

Charges inside the closed surface (*S*) are:

$$Q_1 = +17.7\,\mu C$$

and $$Q_2 = -8.85\,\mu C$$

Net enclosed charge

$$Q_{enc}\ Q_1 + Q_2$$

$$Q_{enc} = 17.7 - 8.85 = 8.85\,\mu C$$

$$Q_{enc} = 8.85 \times 10^{-6}\ C$$

$$\Phi = \frac{8.85 \times 10^{-6}}{8.85 \times 10^{-12}}$$

$$\Phi = 10^6\ Nm^2/C$$

OR

(ii) (a) Find the value of current '*I*' in Figure 2 given below.

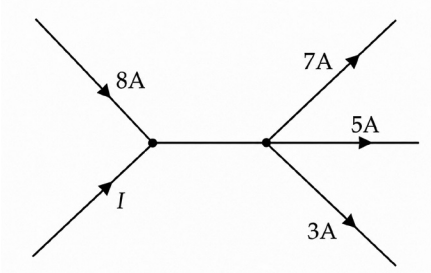

Figure 2

Ans :

According to Kirchhoff's Current Law (KCL), the total current entering a junction is equal to the total current leaving the junction. This is based on the principle of conservation of electric charge..

Currents entering the junction: (8 A) and (I)

Currents leaving the junction 7 A, 5 A and 3 A

$$8 + I = 7 + 5 + 3$$

$$8 + I = 15$$

$$I = 7\ A$$

(b) State the conservation principle on which your calculation is based.

Ans :

The calculation is based on the principle of conservation of electric charge, which states that electric charge can neither be created nor destroyed.

QUESTION 3.

You are provided with three identical capacitors, each of capacitance 'C'.

If C_p is equivalent capacitance when they are connected in parallel and C_s is equivalent capacitance when they are connected in series, calculate the ratio C_s/C_p [2]

Ans :

When three identical capacitors (each C) are connected:

In the parallel combination,

$$C_p = C + C + C = 3\,C$$

In the series combination

$$\frac{1}{C_s} = \frac{1}{C} + \frac{1}{C} + \frac{1}{C}$$

$$C_s = \frac{C}{3}$$

$$\frac{C_s}{C_p} = \frac{\frac{C}{3}}{3C} = \frac{1}{9}$$

QUESTION 4.

(i) What is the effect of doubling the current flowing through a metallic wire on: [2]

(a) drift speed of free electrons?

(b) relaxation time of free electrons?

Ans :

For current in a conductor, drift speed is related to current by

$$I = nqAv_d$$

Since n (electron density), A (area), and e (charge) are constant, the drift speed is directly proportional to the

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current. So if the current is doubled, the drift speed also doubles.

(a) According to drift velocity, $v_d \propto I$
If the current is doubled, the drift speed also becomes double.

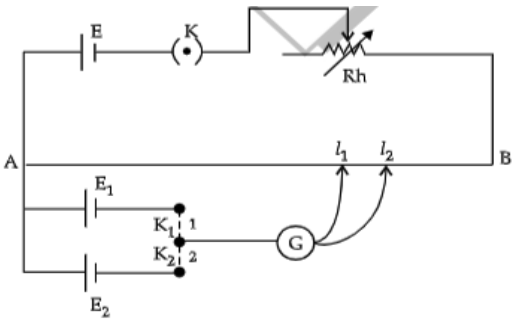
(b) The relaxation time depends on the material and temperature, not on current. Hence doubling the current has no effect on relaxation time.

OR

(ii) Draw a labelled circuit diagram of potentiometer used to compare emfs of two given cells *X* and *Y*. (Procedure and formula are NOT required.)

Ans :

Circuit diagram potentiometer



QUESTION 5.

(i) Write an expression of Biot-Savart law in vector form.

(ii) State Ampere's circuital law. [2]

Ans :

(i) The vector form of the Biot–Savart Law is

$$d\vec{B} = \frac{\mu_0 I\vec{dl} \times \hat{r}}{4\pi r^2}$$

(ii) Ampere's Circuital Law states that the line integral of the magnetic field around a closed path equals (μ_0) times the total current enclosed by the path.

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{enc}$$

QUESTION 6.

A bi-convex lens of focal length f_1 is placed in air as shown in Figure 3(a) below. The radii of curvature of its first and second surfaces are *R* and 2*R* respectively. The lens is cut along the plane CD. Compare the focal length f_2 of the resulting lens shown in Figure 3(b) with that of the original lens shown in Figure 3(a). [2]

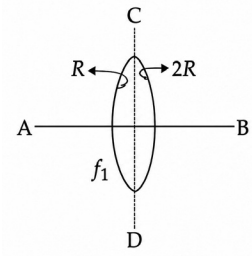


Figure 3 (a)

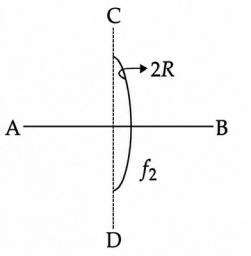


Figure 3 (b)

Ans :

Using the lens maker's formula,

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Original biconvex lens

$$R_1 = R,\ R_2 = -2R$$

$$\frac{1}{f_1} = (\mu - 1)\left(\frac{1}{R} - \frac{1}{-2R}\right)$$

$$\frac{1}{f_1} = (\mu - 1)\left(\frac{1}{R} + \frac{1}{2R}\right)$$

$$\frac{1}{f_1} = \frac{3(\mu - 1)}{2R}$$

After cutting along plane (CD).

One surface becomes plane (R = ∞) and the other retains radius (2R).

Thus the lens becomes plano-convex.

$$\frac{1}{f_2} = (\mu - 1)\left(\frac{1}{\infty} - \frac{1}{-2R}\right)$$

$$\frac{1}{f_2} = \left(\frac{\mu - 1}{2R}\right)$$

Comparison $\frac{\frac{1}{f_1}}{\frac{1}{f_2}} = \frac{\frac{3(\mu-1)}{2R}}{\frac{(\mu-1)}{2R}} = 3$

$$f_2 = 3f_1$$

QUESTION 7.

(i) Name the electromagnetic wave that scans the contents of the luggage of traveller during a security check.

(ii) Which physical quantity is the same for UV rays, red light and radio waves when they are travelling in vacuum? [2]

Ans :

(i) The electromagnetic wave used to scan luggage during security checks is X-rays.

(ii) When Ultraviolet Radiation, Red Light and Radio Waves travel in vacuum, they all have the same speed, which is the speed of light $c = 3 \times 10^8$ m/s

QUESTION 8.

The work functions for metals M_1 and M_2 are 1.9 eV and 5.0 eV respectively. Perform necessary calculations to find out which metal emits photoelectrons, when monochromatic light of wavelength 410 nm is incident on them. [2]

Ans :

For the Photoelectric effect, emission occurs if the photon energy ($\geq$) work function.

The energy of the photon is given by :

$$E = \frac{hc}{\lambda}$$

Using $hc = 1240 \text{ eV.nm}$

$$E = \frac{1240}{410} = 3.02 \text{ eV}$$

After comparison with work functions ,we get

$M_1 : \phi_1 = 1.9 \text{ eV}$

3.02 > 1.9 $\rightarrow$ photoelectrons are emitted

$M_2 : \phi_2 = 5.0 \text{ eV}$

3.02 < 5.0 $\rightarrow$ no photoelectrons are emitted

Metal (M_1) emits photoelectrons, while (M_2) does not.

SECTION-C (27 Marks)

QUESTION 9.

Show the intensity of electric field at a point in end on position i.e., axial position of an electric dipole is given by:

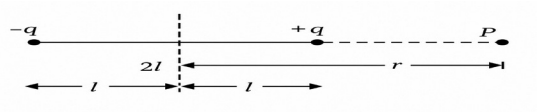
$$E = \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{2pr}{(r^2 - l^2)^2}$$

Where the terms have their usual meaning. [3]

Ans :

Consider an electric dipole consisting of charges (+q) and (-q) separated by distance (2l).

Let the point P be situated at a distance r from the centre of the dipole along its axial (end-on) line.



Distance of point (P) from the charges:

$$r_1 = r - l, \; r_2 = r + l$$

Electric field at (P) due to (+q) is given by

$$E_1 = \frac{1}{4\pi\varepsilon_0}\frac{q}{(r-l)^2}$$

Electric field at (P) due to (-q) is given by

$$E_2 = \frac{1}{4\pi\varepsilon_0}\frac{q}{(r+l)^2}$$

Net electric field along the axis is given by

$$E = E_1 - E_2$$

$$E = \frac{1}{4\pi\varepsilon_0}\left[\frac{q}{(r-l)^2} - \frac{q}{(r+l)^2}\right]$$

$$= \frac{1}{4\pi\varepsilon_0}\left[\frac{(r+l)^2 - (r-l)^2}{(r^2 - l^2)^2}\right]$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{4rl}{(r^2 - l^2)^2}$$

Since, dipole moment ($p = 2ql$),

$$E = \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{2pr}{(r^2 - l^2)^2}$$

QUESTION 10.

(i) In the circuit shown in Figure 4 below, how much resistance should be connected to a 10 Ω resistor so that the points M and N are at the same potential? [3]

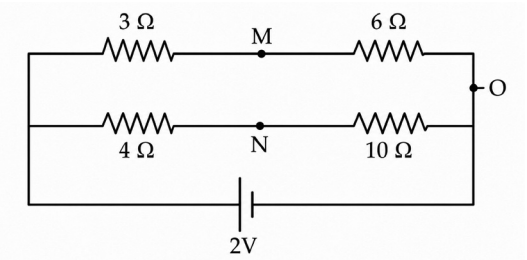


Figure 4

Ans :

Points (M) and (N) will be at the same potential when the potential drops across the left and right parts of both branches are proportional (balanced bridge condition using Ohm's Law).

Thus,

$$\frac{3}{6} = \frac{4}{10 + R}$$

where (R) is the resistance added in series with the (10 Ω) resistor.

$$\frac{1}{2} = \frac{4}{10 + R}$$

$$10 + R = 8$$

$$R = -2\,\Omega$$

The negative sign means the required resistance must reduce the effective resistance of the (10 Ω) branch by (2 Ω).

Hence, the equivalent resistance required (= 8 Ω).

If resistance (R) is connected in parallel with (10 Ω):

$$\frac{10R}{10 + R} = 8$$

$$10R = 80 + 8R$$

$$2R = 80$$

$$R = 40\,\Omega$$

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OR

(ii) Figure below shows a battery consisting of three cells. Their emfs and internal resistances are also shown.

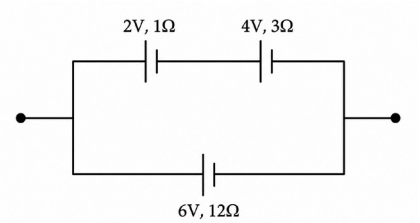


Figure 5

Calculate:

(a) emfs of the battery.

(b) internal resistance of the battery.

Ans :

(a) In the given circuit, the top branch has two cells connected in series combination. :

$$E_1 = 2\text{ V}, r_1 = 1\,\Omega$$

$$E_2 = 4\text{ V}, r_2 = 3\,\Omega$$

$$E_{top} = 2 + 4 = 6\text{ V}$$

$$r_{top} = 1 + 3 = 4\,\Omega$$

The bottom branch having only one cell

$$E_{bottom} = 6\text{ V}, r_{bottom} = 12\,\Omega$$

Since, both branches have the same emf (6 V), the effective emf of the battery remains

$$E = 6\text{ V}$$

(b) Using parallel combination for internal resistance (from Internal Resistance):

$$r = \frac{r_1 r_2}{r_1 + r_2}$$

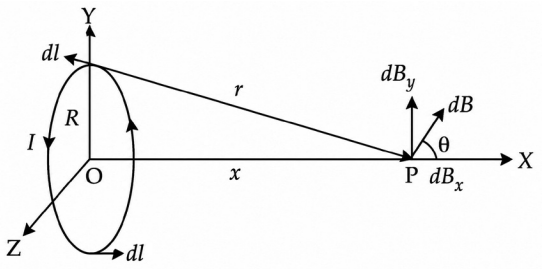
$$= \frac{4 \times 12}{4 + 12} = \frac{48}{16} = 3\,\Omega$$

QUESTION 11.1

(i) Obtain an expression for magnetic field (B) at the centre of a circular coil having '*n*' turns of radius '*R*' when it is carrying current '*I*' [3]

Ans :

Consider a circular coil of radius *R* carrying current *I*.



According Biot–Savart Law:

$$dB = \frac{\mu_0}{4\pi}\frac{Idl\sin\theta}{r^2}$$

At the centre of the coil:

$$r = R$$

The angle between *dl* and *r* is (90°), so (sin θ = 1)

$$dB = \frac{\mu_0 Idl}{4\pi R^2}$$

For the entire circular loop,

$$B = \int dB = \frac{\mu_0 I}{4\pi R^2}\int dl$$

The total length of the circular loop is

$$\int dl = 2\pi R$$

$$B = \frac{\mu_0 I}{4\pi R^2}(2\pi R)$$

$$B = \frac{\mu_0 I}{2R}$$

For a coil having (n) turns, the magnetic fields add up:

$$B = \frac{\mu_0 nI}{2R}$$

OR

(ii) (a) Two moving coil galvanometers G_1 and G_2 are identical except for the following features:

Features	G_1	G_2
Number of turns	50	60
Area of the coil	30 cm²	40 cm²
Resistance of the coil	4 Ω	6 Ω

Performs calculation to determine which galvanometer has greater current sensitivity.

(b) In a moving coil galvanometer, how is magnetic field made radial?

Ans :

(a) The current sensitivity of a moving coil galvanometer is the deflection produced per unit current :

$$S_i = \frac{\theta}{I} = \frac{NBA}{k}$$

Where, N = number of turns, B = magnetic field, A = area of the coil, and k = torsional constant of the suspension.

Thus,

$$S_i \propto NA$$

For galvanometers (G1):

$$N_1 A_1 = 50 \times 30 = 1500$$

For galvanometers (G2):

$$N_2 A_2 = 60 \times 40 = 2400$$

Since, (2400 > 1500)

$$S_{G_2} > S_{G_1}$$

Galvanometer G_2 has greater current sensitivity.

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(b) In a moving coil galvanometer, the magnetic field is made radial by using concave (cylindrical) pole pieces of the permanent magnet along with a cylindrical soft iron core placed at the centre of the coil. This arrangement keeps the plane of the coil always parallel to the magnetic field, so that the deflection becomes directly proportional to the current passing through it

QUESTION 12.

Figure 6 below shows a long straight conductor *X* carrying a current I_1. A point *P* is at a perpendicular distance 'r_1' from it. [3]

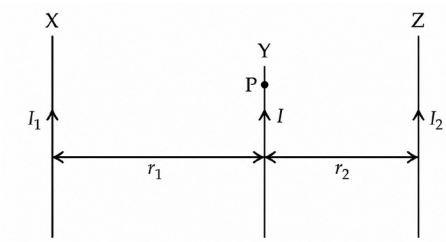

Figure 6

(i) How much force conductor *X* exerts on a short conductor *Y* of length '*l*' which is carrying a current '*I*' and is kept at point *P* parallel to the conductor *X* ?

(ii) Another long wire Z carrying a current I_2 is now kept parallel to X and Y at a distance 'r_2' from Y such that the conductor Y remains at rest. Obtain the relation between the currents I_1 and I_2.

Ans :

(i) Magnetic field at point *P* due to long straight conductor (X) (from Biot–Savart Law) is

$$B = \frac{\mu_0 I_1}{2\pi r_1} \quad \text{.....(i)}$$

Force on a current carrying conductor placed in magnetic field:

$$F = BIl \quad \text{.....(ii)}$$

Substituting the value of the ***B*** from the equation (i),We get

$$F = \left(\frac{\mu_0 I_1}{2\pi r_1}\right) Il$$

$$F = \frac{\mu_0 I_1 Il}{2\pi r_1}$$

Direction: Since currents in (*X*) and (*Y*) are parallel and upward the force is attractive.

(ii) Condition for conductor (*Y*) to remain at rest, Magnetic field at (*Y*) due to (*Z*):

$$B_2 = \frac{\mu_0 I_2}{2\pi r_2}$$

Force on (*Y*) due to (*Z*):

$$F_z = BIl = \frac{\mu_0 I_2 Il}{2\pi r_2}$$

Conductor (Y) remains at rest only when the forces on it are balanced,

$$F_1 = F_z$$

$$\frac{\mu_0 I_1 Il}{2\pi r_1} = \frac{\mu_0 I_2 Il}{2\pi r_2}$$

$$\frac{I_1}{r_1} = \frac{I_2}{r_2}$$

Therefore, the currents are related as

$$I_1 r_2 = I_2 r_1$$

QUESTION 13.

A monochromatic ray of light incident on one refracting surface of an equilateral prism, suffers a deviation as shown in the Figure 7 below. [3]

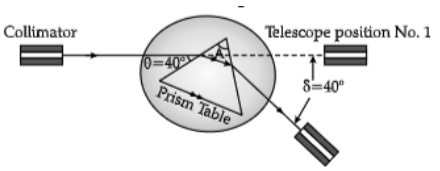

Figure 7 Telescope position No. 2

(i) Calculate the refractive index of the material of the prism.

(ii) What is meant by dispersive power of a transparent material?

Ans :

(i) Given,

Deviation, $\delta = 40^\circ$

For a prism, refractive index is

$$\mu = \frac{\sin\left(\frac{A+\delta}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

For an equilateral prism, A = 60°

On substituting all the values, we obtain

$$\mu = \frac{\sin\left(\frac{60^\circ + 40^\circ}{2}\right)}{\sin\left(\frac{60^\circ}{2}\right)}$$

$$= \frac{\sin 50^\circ}{\sin 30^\circ}$$

$$\sin 50^\circ \approx 0.766, \sin 30^\circ = 0.5$$

$$\mu \approx \frac{0.766}{0.5}$$

$$\approx 1.53$$

(ii) Dispersive power of a transparent material is the ability of the material to separate white light into its constituent colours due to different refractions of different wavelengths of light.

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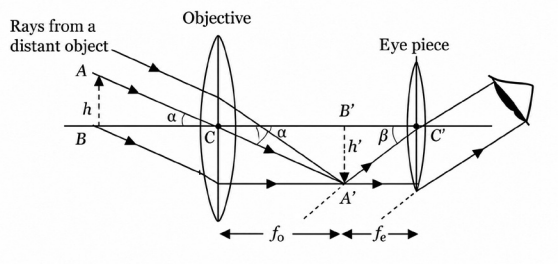
QUESTION 14.

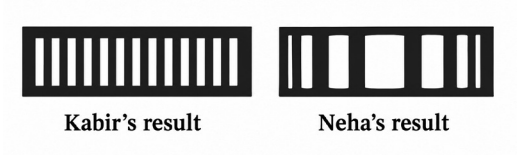
Draw a labelled diagram of an astronomical telescope when its final image lies at infinity. [3]

Ans :



QUESTION 15.

Kabir and Neha conducted experiments on light as part of their school project. Both of them worked with the same source of monochromatic yellow light. Both obtained patterns on the screen which consisted of alternate bright and dark bands.The images below depict their results. [3]



(i) Identify the phenomenon observed by Neha.

(ii) The teacher asked Kabir to replace monochromatic yellow light with white light. What would be Kabir's observation now?

(iii) What conclusion would be drawn by Kabir and Neha about the nature of light?

Ans :

(i) The phenomenon observed by Neha is the diffraction of light. In her pattern, the central bright fringe is much wider and brighter than the side fringes, and the brightness decreases rapidly away from the centre. This is the characteristic feature of single-slit diffraction, unlike interference, where all bright fringes are nearly equal in width and brightness.

(ii) When Kabir replaces the monochromatic yellow light with white light in Young's Double Slit Experiment, he observes:

1. Central white fringe: The central fringe is white, because at the centre the path difference is zero for all wavelengths, so all colours interfere constructively there.
2. Coloured fringes: The fringes on either side are coloured. Since fringe width is proportional to wavelength, violet (shorter wavelength) appears closer to the centre and red (longer wavelength) appears further out.
3. Uniform illumination: After a few coloured fringes, the different colours overlap so much that the pattern disappears, leaving the screen uniformly illuminated..

(iii) Both Kabir and Neha would conclude that light has a wave nature. Kabir's result shows interference and Neha's result shows diffraction, and both of these phenomena can only be explained by treating light as a wave — one that can overlap to produce alternating bright and dark fringes, and bend around obstacles or through narrow slits. Such effects cannot be accounted for by the particle (corpuscular) theory of light. Hence, both observations directly establish the wave nature of light.

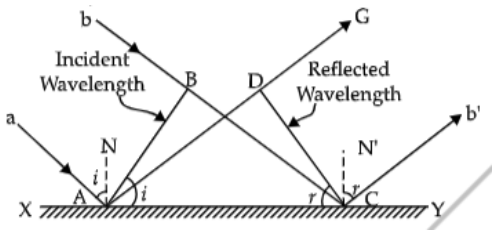
QUESTION 16.

Using Huygen's wave theory and a labelled diagram, show that angle of reflection (r) is equal to angle of incidence (i) [3]

Ans :

Consider a plane wavefront AB incident on a reflecting surface XY. Let c be the speed of light and t be the time taken by point B to reach point C on the reflecting surface. Then, the distance travelled by point B is given by BC=ct. During the same time interval t, the secondary wavelet originating from point A also travels an equal distance to reach point D. Therefore, AD=ct. Consider a plane wavefront AB incident on a reflecting surface XY.

Thus, $BC = AD$



Consider the two right-angled triangles (ΔABC) and (ΔADC):

- AC is common (hypotenuse)
- $BC = AD$ (distance travelled in same time t)
- Both triangles are right-angled (wavefronts are perpendicular to rays)

Consider the two right-angled triangles, ΔABC and Δ ADC. Here, AC is the common hypotenuse for both triangles, and BC=AD because both distances are travelled by light in the same time interval t. Also, both triangles are right-angled since wavefronts are always perpendicular to the direction of propagation of light rays.

Therefore, by RHS congruence:

$$\triangle ABC \cong \triangle ADC$$

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Hence, corresponding angles are equal:

$$\angle BAC = \angle DCA$$

From geometry of the figure:

$$\angle BAC = i \qquad \text{(angle of incidence)}$$

$$\angle DCA = r \qquad \text{(angle of reflection)}$$

Therefore, $i = r$

QUESTION 17.

(i) The graphs below show variation of stopping potential versus frequency of incident radiation for metals *A* and *B*. [3]

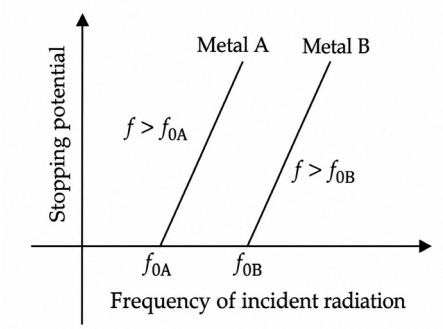

Figure 9

UV radiation of appropriate wavelength is allowed to fall on both the metals. Which metal will emit photoelectrons with higher maximum kinetic energy (E_{max})? Give a reason.

(ii) State the conclusion that was drawn from Davisson-Germer's experiment.

Ans :

(i) Metal (A) emits photoelectrons with higher $E_{\max}$

Reason:

- $V_{0A} < V_{0B} \Rightarrow$ Metal *A* has lower work function (ϕ).
- Using Einstein's photoelectric equation:

$$E_{\max} = h\nu - \varphi$$

- For same incident frequency (ν), smaller $\varphi \Rightarrow$ larger $E_{\max}$

Hence, metal (A) gives higher maximum kinetic energy.

(ii) Davisson-Germer's Experiment Conclusion

The main conclusion of the Davisson-Germer experiment was the experimental confirmation of the wave nature of electrons.

- It verified the de Broglie hypothesis by demonstrating that electrons, like light waves, can undergo diffraction when scattered by a crystal lattice.

SECTION-D (15 Marks)

QUESTION 18.

(i) (a) When a coil is connected to a 200 V dc supply, the current flowing through it is found to be 1 A. However, when it is connected to the 200 V, 50 Hz ac supply, the current is found to be 0.5 A. [5]

1. Explain why current flowing is less when the coil is connected to an ac supply.
2. Calculate the coefficient of self-inductance (*L*) of the coil.

(b) If the power factor in a circuit is 0.5, what is the phase difference between the voltage and the current in the circuit?

Ans :

(a) 1. Reason for Less Current in *AC*

When the coil is connected to a *DC* source, it offers only resistance *R*.

However, in an *AC* circuit, the coil offers resistance *R* as well as inductive reactance X_L.

Thus, total opposition (impedance *Z*) is:

$$Z > R$$

Since, current $I = \frac{V}{Z}$, therefore:

$$I_{AC} < I_{DC}$$

Hence, current is less in *AC* due to the presence of inductive reactance.

2. Given:

$$V = 200\ \text{V}\ \ IDC = 1\ \text{A}$$

$$IAC = 0.5\ \text{A}\ \ f = 50\ \text{Hz}$$

Resistance from DC:

$$R = \frac{V}{I_{DC}} = \frac{200}{1} = 200\ \Omega$$

Impedance from AC:

$$Z = \frac{V}{I_{AC}} = \frac{200}{0.5} = 400\ \Omega$$

Relation between *Z*, *R* and *L* :

$$Z = \sqrt{R^2 + (\omega L)^2}$$

$$400^2 = 200^2 + (\omega L)^2$$

$$(\omega L)^2 = 120000$$

$$\omega L = 346.4$$

Angular frequency:

$$\omega = 2\pi f = 314\ \text{rad/s}$$

Inductance:

$$L = \frac{346.4}{314} \approx 1.1\ \text{H}$$

The inductance of the coil is (1.1 H)

(b) Given: $\cos\varphi = 0.5$

$$\varphi = 60^\circ$$

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OR

(ii) (a) A 70 Ω resistor is connected to an ac source generating an emf 'e' given by

$$e(V) = 495 \sin(100\ \pi t)$$

Calculate *rms* value of the current (I_{rms}) flowing through the resistor.

(b) A 20 cm length of a long iron cored solenoid has 25 turns. If the area of cross section of the solenoid is 1×10^{-4} m^2,
calculate its coefficient of self-inductance (L).

(c) State why soft iron is preferred to steel as a material for the core of a transformer.

Ans :

(a) Given: $e = 495 \sin(100\pi t)$

$= R = 70\ \Omega$

Peak EMF $(e_0) = 495$ V

Peak Current $(I_0) = \frac{495}{70} \approx 7.07$ A

$$I_{rms} = \frac{I_0}{\sqrt{2}} = \frac{7.07}{1.414} \approx 5 \text{ A}$$

(b) Given,
Length of solenoid, (l = 20 cm = 0.2 m)
Number of turns, (N = 25)
Area of cross-section, $A = 1 \times 10^{-4}$ m^2
Relative Permeability, $\mu = 3000$
The self-inductance of a long solenoid is given by:

$$L = \frac{\mu_0 \mu_r N^2 A}{l}$$

$$= \frac{(4\pi \times 10^{-7}) \cdot 3000 \cdot (25)^2 \cdot (1 \times 10^{-4})}{0.2}$$

$$= \frac{12.56 \times 10^{-7} \times 3000 \times 625 \times 10^{-4}}{0.2}$$

$$= 117.8 \times 10^{-5}$$

$$\approx 1.18 \times 10^{-3} \text{ H}$$

(c) Soft iron is preferred over steel for the following technical reasons:

1. Low Hysteresis Loss: Soft iron has a narrow hysteresis loop, meaning the energy dissipated as heat during each cycle of magnetization and demagnetization is very low compared to steel.
2. High Permeability: Soft iron has high magnetic permeability, which allows for better magnetic flux linkage between the primary and secondary coils, increasing the efficiency of the transformer.
3. Low Retentivity and Coercivity: Soft iron loses its magnetism quickly once the current is removed, which is essential for the rapidly changing magnetic fields in AC circuits.

QUESTION 19.

Answer either subparts (i) to (iii) or (iv) to (vii). [5]

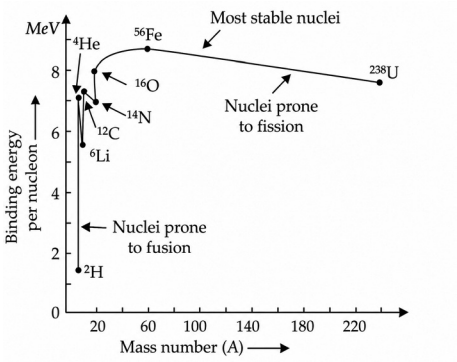
(i) Draw a labelled graph showing the variation of binding energy per nucleon with the mass number (A) of the nucleus. On it, mark the nucleus that is most stable.

(ii) What is meant by the following statement?
'Angular momentum of an orbiting electron is quantised.'

(iii) Calculate the shortest wavelength of Balmer series.

Ans :

(i)



(ii) The statement "Angular momentum of an orbiting electron is quantised" refers to Bohr's Second Postulate.
It means that an electron can revolve only in those orbits for which its angular momentum is an integral multiple of $\frac{h}{2\pi}$, where h is Planck's constant.
Thus, the electron cannot have arbitrary values of angular momentum; it can only exist in certain discrete permitted orbits.
Mathematical Expression:

$$mvr = n\frac{h}{2\pi}$$

Where

m = mass of electron

v = velocity

r = radius of orbit.

n = 1,2,3...

(iii) For Balmer series, electron transition end at $n = 2$
The shortest wavelength corresponds to transition from $n_2 = \infty$
Using Rudberg formula:

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{\infty}\right)$$

$$= R\left(\frac{1}{4}\right)$$

$$\lambda = \frac{4}{R}$$

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Putting $R = 1.097 \times 10^7\ m^{-1}$:

$$\lambda = \frac{4}{1.097 \times 10^7}$$
$$\approx 3.65 \times 10^{-7}\ m$$
$$= 365\ nm$$

OR

(iv) Calculate the minimum amount of energy which a gamma ray photon should possess in order to produce a proton and an anti-proton pair.

(v) Why is a nuclear fusion reaction also known as a thermonuclear reaction?

(vi) What is the physical significance of the fact that total energy of an orbiting electron is negative?

(vii) State any one limitation of Bohr's theory of hydrogen atom.

Ans :

(iv) For pair production:

$$E_{min} = 2m_p c^2$$
$$= 2 \times 938\ MeV$$
$$= 1876\ MeV$$

(v) Nuclear fusion requires extremely high temperature to overcome electrostatic repulsion between positively charged nuclei. Hence, it is called a thermonuclear reaction.

(vi) Significance of negative total energy negative total energy means:

- Electron is bound to the nucleus
- Energy must be supplied to remove it to infinity ($E = 0$).

It indicates a stable bound system.

(vii) Limitation of Bohr's theory : It fails to explain spectra of multi-electron atoms (like helium).

QUESTION 20.

Read the scenario given below and answer the questions that follow.

Annie, a student of Physics, began her experiment by fabricating a p-n junction diode from an extrinsic semiconductor crystal, leading to the formation of a depletion region and a potential barrier at the interface. She then measured resistance of the diode in the linear region of the V-I characteristic curve. She also studied its characteristics during forward bias and reverse bias. Finally, she designed a circuit to convert ac voltage to dc voltage [5]

(i) Which instrument was used by Annie to measure current flowing through the diode during its reverse bias?

(ii) How did Annie obtain an extrinsic semiconductor from an intrinsic semiconductor?

(iii) What is meant by potential barrier?

(iv) Draw a labelled circuit diagram of a half wave rectifier.

Ans :

(i) Instrument used to measure current during reverse bias. During reverse bias, only a very small reverse saturation current (of the order of microamperes, μA) flows through the diode. Therefore, Annie used a microammeter to measure this current.

(ii) Annie obtained the extrinsic semiconductor by the process of doping — that is, by deliberately adding a small, controlled amount of a suitable impurity to the pure (intrinsic) semiconductor crystal.

- Adding pentavalent impurities (like As, P, Sb) creates an *n*-type semiconductor.
- Adding trivalent impurities (like B, Al, In) creates a *p*-type semiconductor.

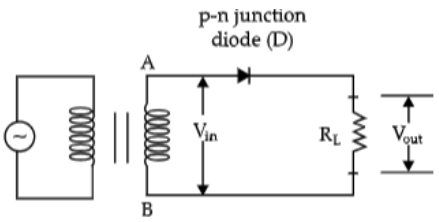
This doping greatly increases the conductivity of the semiconductor.

(iii) When a p-n junction is formed, diffusion of charge carriers across the junction leaves behind immobile charged ions, creating a depletion region. The potential difference developed across this depletion region, which opposes the further diffusion of holes (from p-side to n-side) and electrons (from n-side to p-side), is called the potential barrier (or barrier potential).

It is the minimum potential that must be overcome before majority charge carriers can cross the junction. (Typically ≈ 0.3 V for Ge and ≈ 0.7 V for Si.)

(iv) In a half-wave rectifier, the a.c. input is fed through a transformer to a single diode in series with a load resistance R_L

The diode conducts only during the half cycle in which it is forward biased, so the output is a unidirectional (d.c.) voltage.



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CHAPTER 1

Electric Charge and Field

SUMMARY

1. ELECTRIC CHARGE

Charge is the property associated with matter due to which it produces and experiences electric and magnetic effect. Benjamin Franklin introduced two types of charges namely positive charge and negative charge based on frictional electricity produced by rubbing two unlike objects like amber and wood. The unit of electric charge in SI system is Coulomb(C).

The charge on electron and proton is respectively -1.6×10^{-19} and 1.6×10^{-19}.

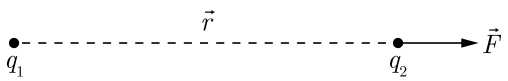
1.1 Properties of Electric Charge

Electric charge have the following properties-

1. **Additivity of Charge :** Charges are scalars and they add up like real numbers. It means of a system consists of n charges q_1, q_2, q_3, ..., q_n then total charge of the system will be $q_1+q_2+q_3+.....+q_n$.
2. **Quantisation of Charge :** The total charge on a body is integral multiple of fundamental charge e, i.e., $q=\pm ne$ where, n is an integer $(n=1,2,3,.....)$.
3. **Conservation of Charge :** The total charge of an isolated system is always conserved, i.e., charge cannot be created or destroyed. It transfer from one body to another body.
4. Like charge repel each other while unlike charge attract each other.

2. COULOMB'S LAW

It states that the electrostatic force of attraction or repulsion acting between two stationary point charges is given by,



$$F=\frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r^2}$$

where, q_1 and q_2 are the stationary point charges and r is the separation between them in air or vacuum.

Also, $$\frac{1}{4\pi\varepsilon_0}=9\times10^9\text{N}-\text{m}^2/\text{C}^2$$

where, ε_0 = permittivity of free space

$$=8.85419\times10^{12}\,\text{C}^2/\text{N}-\text{m}^2$$

The force between two charges q_1 and q_2 located at a distance in a medium other than free space may be expressed as

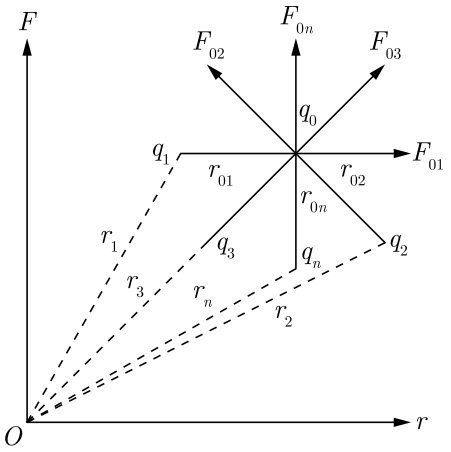
$$F=\frac{1}{4\pi\varepsilon_0}\cdot\frac{q_1q_2}{r^2}$$

In vector form, $$\vec{F}=\frac{1}{4\pi\varepsilon_0}\cdot\frac{q_1q_2}{|\vec{r}|^2}\hat{r}$$

Electrostatic forces are conservatives forces. The direction of electrostatic force between two point charges is along the line joining the two charge.

3. PRINCIPLE OF SUPERPOSITION OF ELECTROSTATIC FORCES

This principle states that the net electric force experienced by a given charge particle q_0 due to a system of charged particles is equal to the vector sum of all the forces exerted on it due to all the other charged particles of the system.



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i.e., $\vec{F}_0 = \vec{F}_{01} + \vec{F}_{02} + \vec{F}_{03} + ... + \vec{F}_{0n}$

$$\vec{F}_0 = \frac{1}{4\pi\varepsilon_0}\left[\frac{q_1 q_0}{|\vec{r}_{01}|^3}\vec{r}_{01} + \frac{q_2 q_0}{|\vec{r}_{02}|^3}\vec{r}_{02} + ... + \frac{q_n q_0}{|\vec{r}_{0n}|^3}\vec{r}_{0n}\right]$$

where, $\vec{r}_{01} = \vec{r}_0 - \vec{r}_{01}$

$\vec{F}_{01}$ = Force on q_0 due to q_1.

Similarly, $\vec{r}_{0n} = \vec{r}_0 - \vec{r}_n$

$\vec{F}_{0n}$ = Force on q_0 due to q_n

Hence, $$\vec{F}_0 = \frac{q_0}{4\pi\varepsilon_0}\left[\sum_{i=1}^{n}\frac{q_i}{|\vec{r}_0 - \vec{r}_i|^3}(\vec{r}_0 - \vec{r}_i)\right]$$

4. ELECTRIC FIELD

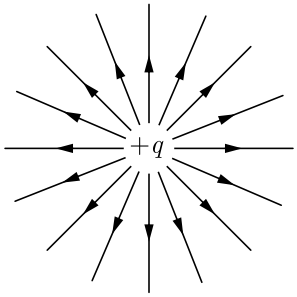
If $\vec{F}$ is the force acting on infinitesimal positive test charge q_0 then electric field strength $\vec{E} = \frac{\vec{F}}{q_0}$, electric field can be given as

$$\vec{E} = \lim_{q_0 \to 0}\frac{\vec{F}}{q_0}$$

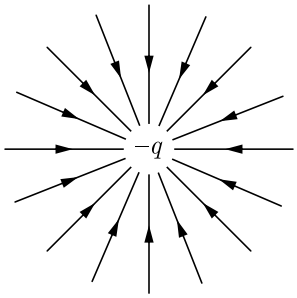
5. ELECTRIC FIELD LINES

Electric field lines are a way of pictorially mapping the electric field around a configuration of charge. These lines start from positive charge and end on negative charge. The tangent on these lines at any point gives the direction of field at that point.

Electric field lines due to positive and negative charge and their combinations are shown as below:

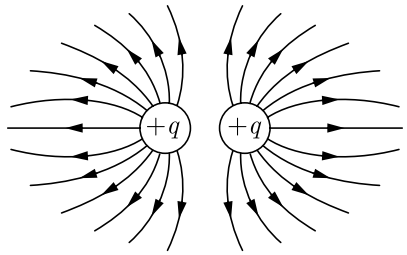


(a)

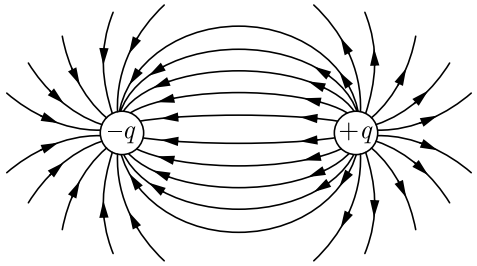


(b)

Electric Field Lines due to Positive and Negative Charge



(c)



(d)

Electric field lines Due to Combination of Charge

6. ELECTRIC FLUX

The total number of electric field lines crossing (or diverging) a surface normally is called electric flux.

Electric flux surface element $\Delta\vec{S}$ is

$$\Delta\phi = \vec{E}\cdot\Delta\vec{S} = E\Delta S\cos\theta$$

where, $\vec{E}$ is electric field strength.

Electric flux through entire closed surface is

$$\phi = \int_S \vec{E}\cdot d\vec{S}$$

7. ELECTRIC DIPOLE

Two point charges of same magnitude and opposite nature separated by a small distance altogether form an electric dipole.

$$\vec{p} = q\cdot 2\vec{l}$$

It is a vector quantity, directed from $-q$ and $+q$.

8. ELECTRIC FIELD DUE TO A SHORT DIPOLE

A point P on axis,

$$E = \frac{1}{4\pi\varepsilon_0}\frac{2p}{r^3}$$

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At a point P' on equatorial plane,

$$E' = -\frac{1}{4\pi\varepsilon_0}\frac{p}{r^3}$$

Torque on an electric dipole placed in a uniform electric field (E) is given by,

$$\tau = p \times E$$

$$|\tau| = pE\sin\theta$$

9. GAUSS'S THEOREM

It states that the total electric flux through a closed surface is equal to $\frac{1}{\varepsilon_0}$ times the net charge enclosed by the surface

i.e., $$\oint_S \vec{E} = d\vec{S} = \frac{1}{\varepsilon_0}\sum q$$

Formulae for Electric Field Strength Calculated from

Electric field due to infinitely long straight wire of charge per unit length λ at a distance r from the wire is

$$E = \frac{1}{4\pi\varepsilon_0}\frac{2\lambda}{r}$$

Electric field strength due to an infinite plane sheet of charge per unit are σ is

$$E = \frac{\sigma}{2\varepsilon_0},$$

independent of distance of a point from the sheet.

Electric field strength due to a uniformly charged thin spherical shell or conducting sphere of radius R having total charge q, at a distance r form centre is

1. At external point $E_{ext} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{r^2}(r > R)$
2. At surface point $E_S = \frac{1}{4\pi\varepsilon_0}\frac{q}{R^2}$
3. At internal point $E_{\text{int}} = 0$.

OBJECTIVE QUESTIONS

1. When a soap bubble is given a positive charge, then its radius

(a) decreases

(b) increases

(c) remains unchanged

(d) nothing can be predicted as information is insufficient

Ans : **Main 2022 Sem-I**

Positive charges get distributed on the surface of the bubble. These positive charges repel each other because like charges repel. Hence, the surface area increase.

Thus (b) is correct option.

2. Ampere-hour is unit of

(a) Power

(b) Charge

(c) Energy

(d) Potential difference

Ans : **SQP 2017**

An ampere-hour is the amount of energy charge in battery that will allow one ampere of current to flow for one hour.

Thus (b) is correct option.

3. When a body is connected to the earth, then electrons from the earth, flow into the body. It means that the body is

(a) unchanged

(b) an insulator

(c) positively charged

(d) negatively charged

Ans : **Main 2025**

We know that when a positively charged body is connected to the earth, then electrons from the earth flow into the body.

Thus (c) is correct option.

4. Permittivity of free space is.

(a) $9 \times 10^9\,\text{mF}^{-1}$ (b) $1.6 \times 10^{-19}\,\text{C}$

(c) $8.85 \times 10^{-12}\,\text{Fm}^{-1}$ (d) $8.85 \times 10^{-9}\,\text{Fm}^{-1}$

Ans : **Comp 2012, 2010**

The permittivity of free space (vacuum) is a physical constant equal to approximately 8.85×10^{-12} farad per meter. It is symbolized ε_0. It is constant of proportionality that exists between electric displacement and electric field intensity in free space.

Thus (c) is correct option.

5. Two point charges $(+e)$ and $(-e)$ are kept inside a large metallic cube without touching its sides. Electric flux emerging out of the cube is

(a) $\frac{e}{\varepsilon_0}$ (b) $\frac{-e}{\varepsilon_0}$

(c) zero (d) $\frac{2e}{\varepsilon_0}$

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Ans : **Main 2011**

The electric flux, emanating through the cube is zero. Since, total charge inside the cube is zero.

Thus (c) is correct option.

6. When a body is charged, its mass-

(a) increase

(b) decrease

(c) remains same

(d) may increase or decrease

Ans : **SQP 2017**

Since we know that charging of a body depends upon transfer of electrons so, if a body becomes negatively charged it will gain electrons that is its mass will increase and when body becomes positively charged it loose the electron that is its mass will decrease.

Thus (d) is correct option.

7. Which one of the following is not a property of electric lines of force?

(a) They originate at the positive charge.

(b) They terminate at the negative charge.

(c) They intersect each other.

(d) A tangent drawn to a line of force gives the direction of electric field intensity at that point.

Ans : **Main 2022 Sem-I**

Electric lines of force do not intersect each other. If they do, then there will be two directions of force at a point which is not possible.

Thus (c) is correct option.

8. Relative permittivity of water is 81. Ifs ε_w and ε_0 are permittivities of water and vacuum respectively, then

(a) $\varepsilon_0 = 9\varepsilon_w$ (b) $\varepsilon_0 = 81\varepsilon_w$

(c) $\varepsilon_w = 9\varepsilon_0$ (d) $\varepsilon_w = 81\varepsilon_0$

Ans : **Main 2024**

We know that relative permittivity

$$\varepsilon_r = \frac{\varepsilon_w}{\varepsilon_0}$$

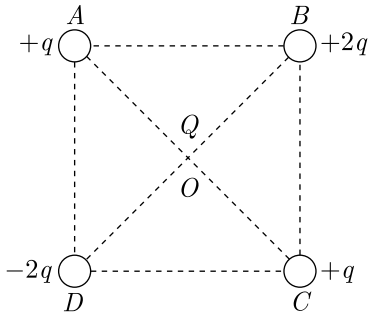
ε_w = absolute permittivity of water

$$= (\varepsilon_r)(\varepsilon_0) = (81)(\varepsilon_0) = 81\varepsilon_0$$

For water, relative permittivity, $\varepsilon_r = 81$

Thus (d) is correct option.

9. Four charges are arranged at the corners of a square $ABCD$, as shown in the adjoining figure. The force on the charge Q kept at the centre O is,



(a) zero

(b) along the diagonal AC

(c) along the diagonal BD

(d) perpendicular to side AB

Ans : **Main 2022 Sem-I**

$$\vec{F} = \vec{F}_A + \vec{F}_B + \vec{F}_C + \vec{F}_D$$

But $\vec{F}_A = -\vec{F}_C$ and $\vec{F}_B = -\vec{F}_D$

$$\vec{F} = 0$$

Thus (a) is correct option.

10. An electric dipole consists of two point charges +2 mC and – 2 mC separated by a distance of 4 cm. It is kept at an angle of 30° with an electric field intensity of $1 \times 10^5\ \text{NC}^{-1}$. The torque experienced by the dipole is

(a) 1 N-m (b) 2 N-m

(c) 3 N-m (d) 4 N-m

Ans : **Main 2022 Sem-I**

$$\text{Torque } (\tau) = pE\sin\theta = q \cdot 2lE\sin\theta$$

$$= 2 \times 10^{-3} \times 4 \times 10^{-2} \times 1 \times 10^5 \sin 30^\circ$$

$$= 4 \text{ N-m}$$

Thus (d) is correct option.

11. The ratio of forces between two small spheres having a constant charge q when placed in air to when placed in a medium of dielectric constant K is

(a) $1 : K$ (b) $K : 1$

(c) $1 : K^2$ (d) $K^2 : 1$

Ans : **Main 2022 Sem-I**

Initial force,

$$F_a = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

Force when placed in medium,

$$F_m = \frac{1}{4\pi\varepsilon}\frac{q_1 q_2}{r^2}$$

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$$\frac{F_a}{F_m} = \frac{\varepsilon}{\varepsilon_0}$$

$$\frac{F_a}{F_m} = K$$

Hence, the ratio is $K : 1$. Thus (b) is correct option.

12. The force between two point charges separated by a certain distance in air is F. If each of the two charges be halved and the distance between them be also halved, the new force would be

(a) F (b) $2F$

(c) $3F$ (d) $4F$

Ans : **Main 2022 Sem-I**

According to Coulomb's law, $F \propto \frac{q_1 q_2}{r^2}$

Now, $q_1' = \frac{q_1}{2}$, $q_2' = \frac{q_2}{2}$ and $r' = \frac{r}{2}$

Now, $F' \propto \frac{q_1' q_2'}{r'^2}$

Now, $F' \propto \frac{\frac{q_1}{2} \times \frac{q_2}{2}}{\left(\frac{r}{2}\right)^2} = F$

Thus (a) is correct option.

13. A body has a positive charge of 8×10^{-19} C. It has

(a) an excess of 5 electrons.

(b) a deficiency of 5 electrons.

(c) an excess of 8 electrons.

(d) a deficiency of 8 electrons.

Ans : **Main 2012**

Here, positive charge $= 8 \times 10^{-19}$ C

As we know from quantisation of charge, $Q = ne$

Charge on one electron, $e = 1.6 \times 10^{-19}$ C

and $n =$ number of electrons transferred

Number of electrons transferred,

$$n = \frac{Q}{e}$$

$$= \frac{8 \times 10^{-19}}{1.6 \times 10^{-19}} = 5$$

The body will have deficiency of 5 electrons, because it is having positive charge.

Thus (b) is correct option.

14. A charge placed at a distance form a short electric dipole in the end on position experience a force F. If the distance is halved, then the force will become

(a) $4F$ (b) $8F$

(c) $F/4$ (d) $F/8$

Ans : **Main 2022 Sem-I**

Electric field due to electric dipole is

$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{2\vec{p}}{r^3} \Rightarrow \vec{F} = \left(\frac{1}{4\pi\varepsilon_0}\frac{2\vec{p}}{r^3}\right)q$$

$$|\vec{E}| \propto \frac{1}{r^3} \Rightarrow \vec{F} \propto \frac{1}{r^3}$$

Now, distance is halved, then new force is

$$\vec{F}' \propto \frac{1}{\left(\frac{r}{2}\right)^3}$$

$$\vec{F}' \propto \frac{8}{r^3} \text{ or } \vec{F}' = 8\vec{F}$$

Thus (b) is correct option.

15. The surface charge density of a large conducting sheet is $17.7 \times 10^{-6}\,\text{Cm}^{-2}$. The electric field intensity at a point outside the sheet but close to it is

(a) $1 \times 10^4\,\text{NC}^{-1}$ (b) $5 \times 10^4\,\text{NC}^{-1}$

(c) $1 \times 10^5\,\text{NC}^{-1}$ (d) $1 \times 10^6\,\text{NC}^{-1}$

Ans : **SQP 2023**

$$E = \frac{\sigma}{2\varepsilon_0}$$

$\varepsilon_0 = 8.85 \times 10^{-12}\,\text{C}^2\text{N}^{-1}\text{m}^{-2}$

$\sigma =$ Surface charge density

$= 17.7 \times 10^{-6}\,\text{Cm}^{-2}$

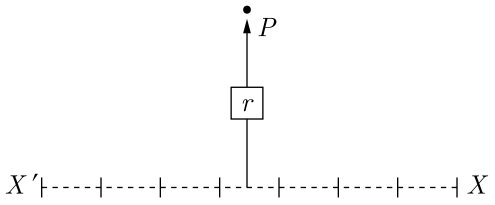
$$E = \frac{\sigma}{2\varepsilon_0}$$

$$= \frac{17.7 \times 10^{-6}\,\text{Cm}^{-2}}{2 \times 8.85 \times 10^{-12}\,\text{C}^2\text{N}^{-1}\text{m}^{-2}}$$

$$= 1 \times 10^6\,\text{NC}^{-1}$$

Thus (d) is correct option.

16. In the figure given below, electric field intensity 'E ' at a point P, at a perpendicular distance r from an infinitely long line charge $X'X$ having linear charge density λ, is given by



(a) $E = \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{2\lambda}{r^2}$ (b) $E = \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{2\lambda}{r}$

(c) $E = \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{\lambda}{r^2}$ (d) $E = \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{\lambda}{r}$

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Ans : **Main 2022 Sem-I**

As we know that

$$E = \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{2\lambda}{r}$$

Thus (b) is correct option.

17. A hollow sphere of radius R has a point charge Q at its centre. Electric flux emanating from it is ϕ. If both the charge and the radius of the sphere be doubled, electric flux emanating from the sphere will

(a) remains the same (b) becomes 2ϕ

(c) becomes 4ϕ (d) becomes 8ϕ

Ans : **SQP 2018, 2015**

Gauss' law,

$$\phi = \frac{Q_{\text{enclose}}}{\varepsilon_0}$$

$$\phi \propto Q_{\text{enclose}}$$

Thus, if Q_{enclose} is double, then electric flux (ϕ) becomes 2ϕ.

Thus (b) is correct option.

18. Intensity of electric field at a point at a perpendicular distance r from an infinite line charge, having linear charge density λ is given by

(a) $\vec{E} = \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{\lambda}{r}$ (b) $\vec{E} = \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{2\lambda}{r}$

(c) $\vec{E} = \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{\lambda}{r^2}$ (d) $\vec{E} = \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{2\lambda}{r^2}$

Ans : **Main 2014**

By applying Gauss's law, electric field due to an infinitely long line charge of line as charge density λ is

$$E = \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{2\lambda}{r}$$

where, r is perpendicular distance from the charged wire.

Thus (b) is correct option.

19. 1 stat-coulomb = ... coulomb.

(a) 3×10^9 (b) 3×10^{-9}

(c) $\frac{1}{3} \times 10^9$ (d) $\frac{1}{3} \times 10^{-9}$

Ans : **SQP 2008**

One stat-coulomb of charge is that charge which when placed at a distance of 1 cm in air from an equal and similar charge repels it and it is also repelled by it with a force of one dyne.

$$1 \text{ stat-coulomb} = 3 \times 10^9 \text{ coulomb}$$

Thus (a) is correct option.

20. The electric field at a point near an infinite thin sheet of charged conductor is

(a) $\varepsilon_0\sigma$ (b) $\frac{\sigma}{\varepsilon_0}$

(c) $\frac{\sigma}{2\varepsilon_0}$ (d) $\frac{1}{2}\sigma\varepsilon_0$

Ans : **Main 2015**

The electric field at a point near an infinite thin sheet of charged conductor is given by,

$$\vec{E} = \frac{\sigma}{2\varepsilon_0}$$

where, σ = Surface Charge Density

ε_0 = Permittivity of free space

Thus (c) is correct option.

21. The electric flux emanating from a sphere of radius 2 m is ϕ. If radius of the sphere be made four times, without changing the charge enclosed, electric flux would

(a) become $\phi/4$ (b) become $\phi/2$

(c) become 2ϕ (d) remain ϕ

Ans : **Main 2022 Sem-I**

According to Gauss's law,

$$\phi = \frac{Q_{\text{enclosed}}}{\varepsilon_0}$$

Thus, if Q remains the same, then ϕ also remains the same.

Thus (d) is correct option.

22. The S.I. unit of electric field $\vec{E}$ is

(a) Cm^{-2} (b) NC^{-1}

(c) Am (d) Vm^{-2}

Ans : **SQP 2009**

The electric field intensity at any point due to source charge is defined as the force experienced per unit positive charge placed at that point without disturbing the source charge i.e.,

$$E = \frac{F}{q} = \frac{N}{C} = \text{NC}^{-1}$$

Since, it is equivalent to volt per meter (Vm^{-1}).

Thus (b) is correct option.

23. A closed surface in vacuum encloses charges $-q$ and $+3q$. The total electric flux emerging out of the surface is

(a) zero (b) $\frac{2q}{\varepsilon_0}$

(c) $\frac{3q}{\varepsilon_0}$ (d) $\frac{4q}{\varepsilon_0}$

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Ans : **Main 2019, 2017**

Total electric flux through the closed surface,

$$\phi = \frac{1}{\varepsilon_0}(-q+3q) = \frac{2q}{\varepsilon_0}$$

Where, q is the total charge enclosed by the closed Gaussian (an imaginary) surface.

Thus (b) is correct option.

24. The electric field at a distance 2 cm from the centre of a hollow spherical conducting shell of radius 4 cm having a charge of 2×10^{-3} C on its surface, is

(a) zero

(b) $1.1 \times 10^{10}\,\text{V-m}^{-1}$

(c) $4.5 \times 10^{-10}\,\text{V-m}^{-1}$

(d) $4.5 \times 10^{+10}\,\text{V-m}^{-1}$

Ans : **Main 2025, 2006**

Distance of point from centre, $x = 2\,\text{cm}$

Radius of shell, $r = 4\,\text{cm}$

We know the electric field inside a hollow spherical conducting shell is zero as potential inside the spherical shell is same at all points.

Thus (a) is correct option.

25. Three point charges are placed at the corners of an equilateral triangle. Assuming only electrostatic forces are acting, the system

(a) Can never be in equilibrium

(b) Will be in equilibrium if charges rotate about the centre of the triangle

(c) Will be in equilibrium if charges have same magnitude but different signs

(d) Will be in equilibrium if charges have different magnitudes and different signs

Ans : **SQP 2014, 2010**

We know that when three point charges are placed at the corners of an equilateral triangle, then some electrostatic forces will act on the system. As a result of this, the system can never be in equilibrium.

Thus (a) is correct option.

26. The specific charge of electron is

(a) $1.8 \times 10^{-11}\,\text{C/kg}$ (b) $1.8 \times 10^{-19}\,\text{C/kg}$

(c) $1.9 \times 10^{-19}\,\text{C/kg}$ (d) none of these

Ans : **SQP 2014**

Specific charge of electron

$$= \frac{\text{Charge an electron}}{\text{Mass of the electron}}$$

$$= \frac{1.6 \times 10^{-19}}{9.1 \times 10^{-31}}$$

$$= 0.1758 \times 10^{-12}\,\text{C/kg}$$

$$= 1.758 \times 10^{11}\,\text{C/kg}$$

$$\approx 1.8 \times 10^{11}\,\text{C/kg}$$

Thus (a) is correct option.

27. Electric intensity due to an electric dipole varies with distance r as $E \propto r^n$, where n is equal to

(a) 0 (b) -1

(c) -2 (d) -3

Ans : **Main 2001**

Here,

Electric intensity due to an electric dipole,

$$E \propto r^n \qquad ...(1)$$

We know that electric intensity due to an electric dipole varies inversely as cube of he distance of he point,

i.e., $$E \propto \frac{1}{r^3} \qquad ...(2)$$

Comparing the Eq. (1) with (2), we get

$$n = -3$$

Thus (d) is correct option.

28. The magnitude of the electric field due to a point charge object at a distance of 4.0 m is 9 N/C. From the same charged object the electric field of magnitude 16 N/C will be at a distance of

(a) 1 m (b) 2 m

(c) 3 m (d) 6 m

Ans : **Main 2023**

Here, distance, $r = 4\,\text{m}$

$$E = \frac{kq}{r^2} = 9\,\text{N/C}$$

$$\frac{kq}{(4)^2} = 9 \qquad ...(1)$$

and $$\frac{kq}{r^2} = 16 \qquad ...(2)$$

where, r is the distance at which the given charge is kept.

Divide Eq. (1) by (2), we get

$$\frac{r^2}{4^2} = \frac{9}{16}$$

$$r = 3\,\text{m}$$

Thus (c) is correct option.

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29. A point P lies at a distance x from the mid point of an electric dipole on its axis. The electric potential at point P is proportional to

(a) $\frac{1}{x^2}$ (b) $\frac{1}{x^3}$

(c) $\frac{1}{x^4}$ (d) $\frac{1}{x^{1/2}}$

Ans : **Main 2023, 2018**

The electric potential due to electric dipole, $\vec{p} = q\vec{d}$ at a distance x from the mid-point of the dipole is given as :

$$V = \frac{1}{4\pi_{\varepsilon_0}} \times \frac{p\cos\theta}{x^2}$$

where, θ is the angle vector $\vec{r}$ forms with vector $\vec{d}$.

Hence, $V \alpha \frac{1}{x^2}$

Thus (a) is correct option.

30. An electric dipole consists of a positive and negative charge of 4 μC each placed at a distance of 5 mm. The dipole moment is

(a) 2×10^{-8} C-m (b) 4×10^{-8} C-m

(c) 6×10^{-8} C-m (d) 8×10^{-8} C-m

Ans : **SQP 2003**

Here,

Magnitude of each charge on dipole,

$$q = 4\,\mu\text{C} = 4 \times 10^{-6}\,\text{C}$$

and distance between the charges,

$$2a = 5\,\text{mm} = 5 \times 10^{-3}\text{m}$$

Dipole moment, $p = q \times 2a$

$$= (4 \times 10^{-6}) \times (5 \times 10^{-3})$$

$$= 2 \times 10^{-8}\,\text{C-m}$$

Thus (a) is correct option.

31. Two charged spheres separated by a distance d exert some force F on each other. If they are immersed in a liquid of dielectric constant 4, then what is the force exerted, if all other conditions are same?

(a) $2F$ (b) $4F$

(c) $\frac{F}{2}$ (d) $\frac{F}{4}$

Ans : **Main 2016**

Distance between two charged sphere $= d$

and dielectric constant of liquid, $K = 4$

We know from the Coulomb's law that force between two charged spheres,

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2} \quad ...(1)$$

and force between two charged spheres when they are immersed in a dielectric medium,

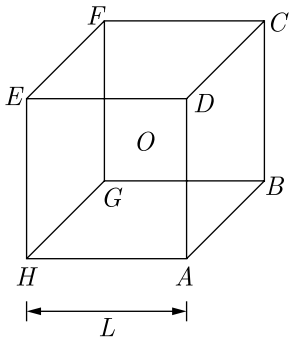
$$F' = \frac{1}{K} \times \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

From Eq. (1), we get

$$F' = \frac{F}{K} = \frac{F}{4}$$

Thus (d) is correct option.

32. A short electric dipole which consists of two point charges $-q$ and $+q$, is placed at the centre O and inside a large cube ($ABCDEFGH$) of length L as shown in the figure. The electric flux emanating through the cube is



(a) $q/4\pi\varepsilon_0 L$ (b) zero

(c) $q/2\pi\varepsilon_0 L$ (d) $q/3\pi\varepsilon_0 L$

Ans : **Main 2015**

The electric flux, emanating through the cube is zero. Since, total charge inside the cube is zero.

Thus (b) is correct option.

33. Two insulated charged copper spheres A and B each having charge of 6.5×10^{-7} C are separated by a distance 50 cm. If they are placed in water of dielectric constant 80, then electrostatic force of repulsion between them is

(a) 1.9×10^{-7} N (b) 3.8×10^{-7} N

(c) 1.9×10^{-4} N (d) 3.8×10^{-4} N

Ans : **Main 2010**

Here,

Charge on sphere A, $q_1 = 6.5 \times 10^{-7}$ C

Charge on sphere B, $q_2 = 6.5 \times 10^{-7}$ C

Distance between the charges,

$$r = 50\,\text{cm}$$

$$= 0.5\,\text{m}$$

Dielectric constant, $K_m = 80$

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We know from the Coulomb's law that electrostatic force of repulsion (due to similar charges), between two spheres when they are placed in a dielectric medium,

$$F = \frac{k}{K_m} \cdot \frac{q_1 q_2}{r^2}$$

Where, k = Electrostatic force constant

$$= 9 \times 10^9 \text{ N-m}^2\text{-C}^{-2}.$$

$$= \frac{(9 \times 10^9)}{80} \times \frac{(6.5 \times 10^{-7}) \times (6.5 \times 10^{-7})}{(0.5)^2}$$

$$= 1.9 \times 10^{-4} \text{ N}$$

Thus (c) is correct option.

34. Three charges, each equal to $+q$, are placed at the corners of an equilateral triangle. If the force between any two charges is F, then net force on either charge will be

(a) $2F$ (b) $3F$

(c) $\sqrt{2}\,F$ (d) $\sqrt{3}\,F$

Ans : SQP 2009, 2007

First charge, $q_1 = q$

Second charge, $q_2 = q$

Third charge, $q_3 = q$

Force between any two charge

$$= F_1 = F_2 = F$$

We know that force acting on a charge due to other two charges, placed at the corners of an equilateral triangle is F and it is acting at an angle 60°.

Therefore net force on either charge

$$= \sqrt{F_1^2 + F_2^2 + 2F_1F_2\cos\theta}$$

$$= \sqrt{F^2 + F^2 + 2F.F\cos 60^\circ}$$

$$= \sqrt{F^2 + F^2 + 2F^2 \times 0.5}$$

$$= \sqrt{3F^2}$$

$$= \sqrt{3}\,F$$

Thus (d) is correct option.

35. A charge q is placed at the centre of the line joining two equal point charges each equal to $+Q$. The system of three charges will be in equilibrium, if q is equal to

(a) $-\frac{Q}{4}$ (b) $+\frac{Q}{4}$

(c) $-\frac{Q}{2}$ (d) $+\frac{Q}{2}$

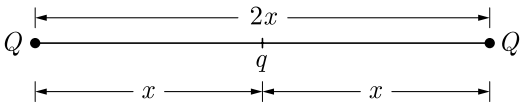
Ans : SQP 2016

Given,

Charge placed at centre $= q$

Two equal point charges $= +Q$

We know from the Coulomb's law that electrostatic force at charge Q due to the other charge at Q.



$$F_1 = k \cdot \frac{Q \cdot Q}{(2x)^2}$$

$$= k \cdot \frac{Q^2}{4x^2}$$

where, $2x$ = Distance between the point charges.

Similarly, force at the same charge Q due to charge q at the centre,

$$F_2 = k \cdot \frac{qQ}{x^2}$$

We also know that for equilibrium, sum of these two forces should be equal to zero. Therefore,

$$0 = k \cdot \frac{Q^2}{4x^2} + k \cdot \frac{qQ}{x^2}$$

$$q = -\frac{Q}{4}$$

Thus (a) is correct option.

36. Two point charges each equal to $2\,\mu\text{C}$ are 0.5 m apart. If both of them exist inside vacuum, then electrostatic force between them is

(a) 0.144 N (b) 0.288 N

(c) 1.44 N (d) 2.88 N

Ans : SQP 2012

Here,

First charge, $q_1 = 2\,\mu\text{C} = 2 \times 10^{-6}\,\text{C}$

Second charge, $q_2 = 2\,\mu\text{C} = 2 \times 10^{-6}\,\text{C}$

and distance between the charge, $r = 0.5\,\text{m}$

We know from the Coulomb's law that electrostatic force between two point charges in vacuum is given by,

$$F = k \cdot \frac{q_1 q_2}{r^2}$$

Here, K = Electrostatic force constant

$$= 9 \times 10^9 \text{ N} - \text{m}^2\text{C}^{-2}$$

Hence, $F = (9 \times 10^9) \times \frac{(2 \times 10^{-6}) \times (2 \times 10^{-6})}{(0.5)^2}$

$$= 0.144 \text{ N}$$

Thus (a) is correct option.

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37. Two point charge Q and $-2Q$ are placed at some distance apart. If the electric field at the location of Q is E, then the electric field at the location of $-2Q$ will be

(a) $-\frac{E}{2}$ (b) $-\frac{3E}{2}$

(c) $-E$ (d) $-2E$

Ans : **Main 2005, 2001**

First charge, $q_1 = Q$

Second charge, $q_2 = -2Q$

and electric field at the location of first charge due to second charge only,

$$E_1 = E$$

Electric field at the location of Q due to second charge,

$$E_1 = k \cdot \frac{q_2}{r^2} \propto q_2$$

Therefore, $$\frac{E_1}{E_2} = \frac{q_2}{q_1} = \frac{-2Q}{Q} = -2$$

$$E_2 = -\frac{E_1}{2} = \frac{E}{2}$$

where, E_2 = Electric field at the location of $-2Q$
Thus (a) is correct option.

38. The electric field required to keep a water drop of mass m just to remain suspended, when charged with one electron, is

(a) $m\,g$ (b) $e\,m\,g$

(c) $\frac{m\,g}{e}$ (d) $\frac{e\,m}{g}$

Ans : **SQP 2013**

Here,

Mass of water drop $= m$

Weight of water drop,

$$w = mg$$

Charge on drop, $q = e$

Where, e = Charge on one electron

Electrostatic force on the water drop due to electric field,

$$= qE = eE$$

Since, the water drop is to remain suspended due to electrostatic force, therefore weight of the water drop should be equal to the electrostatic force.

Thus, $$mg = eE$$

$$E = \frac{mg}{e}$$

(where, E = Electric field required)

Thus (c) is correct option.

39. Two point charge A and B of charge $+4\,\mu C$ and $-1\,\mu C$ are placed in air at a distance 1 m apart. The distance of the point from the charge B on the line joining the charges, where the resultant electric field is zero, is

(a) 0.5 m (b) 1 m

(c) 1.5 m (d) 2 m

Ans : **Main 2017, 2012**

Here,

Charge at A, $q_A = +4\,\mu C$

Charge at B, $q_B = -1\,\mu C$

Distance between the charges $= 1\,m$.

If x is the distance between the point (where, resultant electric field is zero) and charge B, then distance between this point and charge.

$$A = 1 + x$$

Electric field at this point due to charge A,

$$E_1 = k \cdot \frac{q_A}{r_1^2} = k \cdot \frac{4}{(1+x)^2}$$

$$= \frac{4k}{(1+x)^2}$$

Similarly, electric field at this point due to charge B,

$$E_2 = k \cdot \frac{q_B}{r_2^2}$$

$$= k \cdot \frac{(-1)}{x^2} = -\frac{k}{x^2}$$

Since the resultant electric field is zero. Therefore,

$$0 = \frac{4k}{(1+x)^2} - \frac{k}{x^2}$$

$$\frac{1}{x^2} = \frac{4}{(1+x)^2}$$

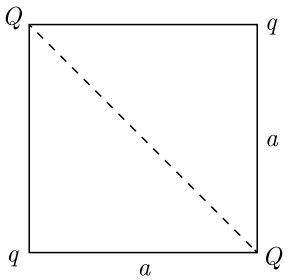
$$\frac{1}{x} = \frac{2}{1+x}$$

$$2x = 1 + x$$

$$x = 1\,m$$

Thus (b) is correct option.

40. In the figure, if net force on Q is zero then value of $\frac{Q}{q}$ is :



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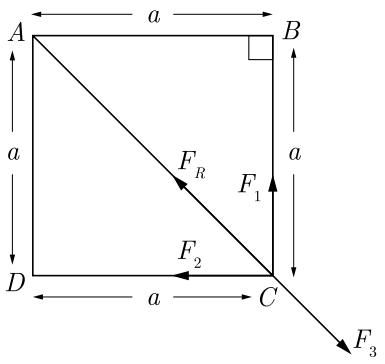
(a) $\sqrt{2}$ (b) $2\sqrt{2}$

(c) $\dfrac{1}{2\sqrt{2}}$ (d) $\dfrac{1}{\sqrt{2}}$

Ans : **Main 2012**

According to the question,we can draw the following



According to Pythagorean theorem in ΔABC

$$AC^2 = AB^2 + BC^2$$

$$AC = \sqrt{a^2 + a^2}$$

$$= \sqrt{2}\, a$$

Resultant force, $F_R = \sqrt{F_1^2 + F_2^2}$ ...(1)

According to coulomb's law,

$$F_1 = \frac{KQq}{a^2}$$

Similarly, $$F_2 = \frac{KQq}{a^2}$$

$$F_3 = \frac{KQQ}{(\sqrt{2}\, a)^2}$$

$$= \frac{KQ^2}{2a^2}$$

From equation (1),

$$F_R = \sqrt{\left(\frac{KQq}{a^2}\right)^2 + \left(\frac{KQq}{a^2}\right)^2}$$

$$= \sqrt{\left(\frac{KQq}{a^2}\right)^2 (1+1)}$$

$$= \frac{KQq\sqrt{2}}{a^2}$$

Since, $F_R - F_3 = 0$

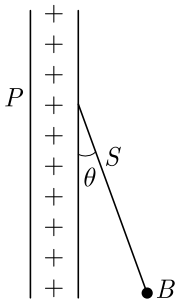
$$F_R = F_3$$

$$\frac{KQq\sqrt{2}}{a^2} = \frac{KQ^2}{2a^2}$$

$$\frac{Q}{q} = 2\sqrt{2}$$

Thus (b) is correct option.

41. A charged ball B hangs from a silk thread S, which makes an angle θ with a large charged conducting sheet P, as shown in the figure. The surface charge density σ of the sheet is proportional to



(a) $\sin\theta$ (b) $\cos\theta$

(c) $\tan\theta$ (d) $\cot\theta$

Ans : **SQP 2011**

Here,

Angle between thread and sheet $= \theta$ and surface charge density $= \sigma$.

We know that electric field due to conducting sheet,

$$E = \frac{\sigma}{2\varepsilon_0}$$

Therefore, force on the ball due to conducting sheet,

$$F = q\,E$$

$$= q \times \frac{\sigma}{2\varepsilon_0} = \frac{q\sigma}{2\varepsilon_0}$$

We also know that in equilibrium, horizontal component of tension in thread is equal to the force on ball due to conducting sheet i.e.,

$$T\sin\theta = \frac{q\sigma}{2\varepsilon_0} \quad ...(1)$$

Similarly, in equilibrium vertical component of the tension in thread is equal to the weight of the ball i.e.,

$$T\cos\theta = mg \quad ...(2)$$

Dividing Eq. (1) by (2),we get

$$\tan\theta = \frac{q\sigma}{2\varepsilon_0 mg}$$

$$\sigma = \frac{2\varepsilon_0 mg\tan\theta}{q}$$

$$\sigma \propto \tan\theta$$

Thus (c) is correct option.

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ASSERTION AND REASON

42. **Assertion (A) :** Work done in moving a charge around a closed path in an electric field is always zero.

Reason (R) : Electrostatic force is a conservative force.

(a) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).

(b) Both Assertion (A) and Reason (R) are true and Reason (R) is NOT the correct explanation of Assertion (A).

(c) Assertion (A) is true and Reason (R) is false.

(d) Assertion (A) is false and Reason (R) is also false.

Ans : **Main 2023**

We know that the work done by the conservative force around any closed path is zero is $\oint F.dl = 0$ and electrostatic force is a conservative force.

Thus (a) is correct option.

43. **Assertion :** For a non-uniformly charged thin circular ring with net charge is zero, the electric field at any point on axis of the ring is zero.

Reason : For a non-uniformly charged thin circular ring with net charge zero, the electric potential at each point on axis of the ring is zero.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **SQP 2015**

For a non-uniformly charged thin circular ring with net zero charge, electric potential at each point on its axis must be perpendicular to the axis.

Thus (d) is correct option.

44. **Assertion :** The electrostatic force between the plates of a charged isolated capacitor decreases when dielectric fills whole space between plates.

Reason : The electric field between the plates of a charged isolated capacitance increases when dielectric fills whole space between plates.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **Main 2017**

For isolated capacitor,

Q = constant,

F = constant,

But, $E = \frac{\sigma}{K\varepsilon_0}$, hence E decreases

Thus (d) is correct option.

ONE MARK QUESTIONS

45. Draw (at least three) electric lines of force due to an electric dipole.

Ans : **Main 2008**

Electric lines of force (field) start from positive charge and ends on negative charge.

46. What is meant by the term quantisation of charge?

Ans : **Main 2015**

The total charge on an object is an integral multiple of charge of an electron, i.e. $q = ne$

Where, n is the number of electrons and e is the elementary charge.

47. A proton is placed in a uniform electric field directed along the position X-axis. In which direction will it bend to move?

Ans : **Comp 2021, 2017**

Proton will tend to move along the X-axis in the direction of a uniform electric field.

48. What is electric charge? Is it a scalar or vector quantity? Name its SI unit.

Ans : **Main 2024**

It is an intrinsic property of elementary particles of matter which gives rise to electric force between various objects. It is a scalar quantity and its SI unit is coulomb(C).

49. Why do the electric field lines never cross each other?

Ans : **Comp 2009**

At the intersection point if electric field lines cross each other, then there would be two directions of electric field which is not possible so lines of forces never cross each other.

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50. A charge q is placed at the centre of a cube of side l. What is the electric flux passing through two opposite faces of the cube?

Ans : SQP 2016

By symmetry, the flux through each of the six faces of the cube will be same when charge q is placed at its centre.

$$\phi_E = \frac{1}{6} \cdot \frac{q}{\varepsilon_0}$$

51. Atmosphere is not electrically neutral. Explain why?

Ans : Main 2020

The atmosphere is continuously being charged by thunderstorms and lightning bolts all over the globe. This maintains an equilibrium with the discharge of the atmosphere in ordinary weather conditions.

52. Explain the statement, relative permittivity of water is 81.

Ans : Main 2009

Relative permittivity (ε_r) of water is the ratio of absolute permittivity (ε) and permittivity of free space (ε_0).

i.e. $$\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$$

It means that permittivity of water is 81 times that of free space.

53. State Gauss' theorem.

Ans : Main 2020, 2016, 2007

The total electric flux linked with closed surface S is equal $1/\varepsilon_0$ times the total charge inside the surface.

$$\phi = \oint \vec{E} \cdot d\vec{S} = \frac{q}{\varepsilon_0}$$

where, q is the total charge enclosed by the closed Gaussian (an imaginary) surface.

54. How rubbing of the two bodies produces electricity?

Ans : SQP 2016

When we rub two bodies, due to friction, some electrons are transferred from one body to another. The body which gains electrons become negatively charged and which loses electrons become positively charged by equal amount.

55. Why do the electrostatic field lines not form closed loops?

Ans : SQP 2017

Electric field lines start from positive charge and terminate at negative charge. If there is a single positive charge, the field lines start from the charge and terminate at infinity. So, the electric field lines do not form closed loops.

56. Why must electrostatic field at the surface of a charged conductor be normal to the surface at every point? Give reason.

Ans : Main 2019

The work done in moving a charge from one point to another on an equipotential surface is zero. If electric field is not normal, it will have a non-zero component along the surface which would cause work to be done in moving a charge on an equipotential surface.

57. Why must electrostatic field at the surface of a charged conductor be perpendicular to every point on it?

Ans : SQP 2025

As, electric field inside a conductor is always zero. The electric line of force exert. Internal pressure on each other leads to repulsion between like charges. Thus, in order to stable spacing, the electric field lines are normal on the surface.

58. What are the limitations of Coulomb's law?

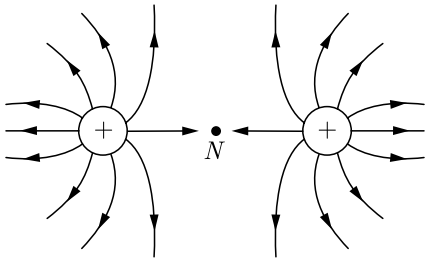
Ans : Comp 2014

The limitation of coulomb's law are following :

1. Coulomb's law has been verified over distances ranging from nuclear dimension ($\simeq 10^{-15}$ m) to macroscopic distance ($\simeq 10^{18}$ m).
2. This law is applicable only to point charge.

59. Draw lines of force of electric field due to a system of two equal point charges.

Ans : Main 2019, 2017



60. What do you mean by additive nature of electric charges?

Ans : SQP 2011

The additivity of electric charge means that the total charge of a system is the algebraic sum of all the individual charges located at different points inside the system. If a system contains charges $q_1, q_2, ..., q_n$; then its total charge is

$$q = q_1 + q_2 + ... + q_n$$

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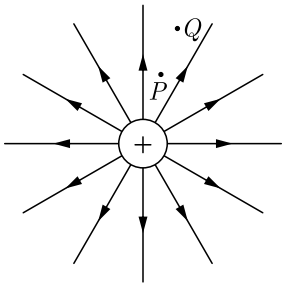
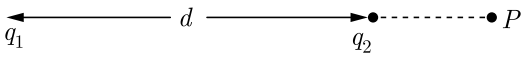
61. Figure shows the field lines on a positive charge is the work done by the field in moving a small positive charge from Q to P positive or negative? Give reason.



Ans : **Comp 2021**

The work done by the field is negative. This is because the charge is moved against the force exerted by the field.

62. Two point charges q_1 and q_2 are placed at a distance d apart as shown in the figure. The electric field intensity is zero at the point P on the line joining them as shown. Write two conclusions that you can draw from this.



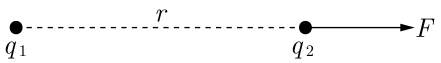
Ans : **SQP 2005**

1. The two point charges (q_1 and q_2) should be of opposite nature.
2. Magnitude of charge q_1 must be greater than magnitude of charge q_2.

63. Write Coulomb's law in vector form.

Ans : **Main 2008**

Vector form of Coulomb's law



$$\vec{F} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q_1 q_2}{|r|^3}\vec{r}$$

or $$|F| = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q_1 q_2}{|r|^2}$$

where, q_1 and q_2 are two charges separated by a distance r which is the displacement vector. It shows direction of force between two charges.

64. Can 8.6×10^{-19} Coulomb of charge be given to a conductor? Explain.

Ans : **Main 2006**

Charge on any conductor can be only an integral multiple of charge present on one electron (quantisation of charge).

Then, $q = ne$

where, $n = 1, 2, 3, ...$

Now, $$n = \frac{8.6 \times 10^{-19}}{1.6 \times 10^{-19}} = 5.4$$

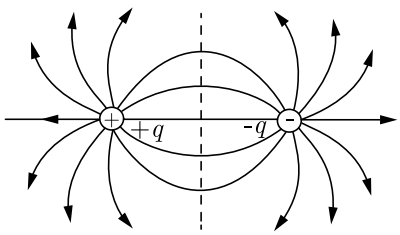
[this is a fraction and not an integer]

So, 8.6×10^{-19} C of a charge cannot be given to a conductor.

65. In an electric dipole, what is the locus of a point having zero potential?

Ans : **Main SQP 2023**

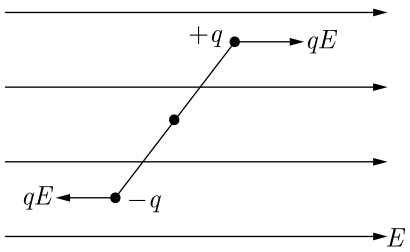
It is a straight line passing through the mid-point and perpendicular to the dipole axis (an equatorial plane).



66. What will be the net electric force acting on an electric dipole placed in a uniform electric field?

Ans : **Main 2007**

Consider the diagram. Total force on the dipole placed in a uniform electric field $\vec{E}$ is

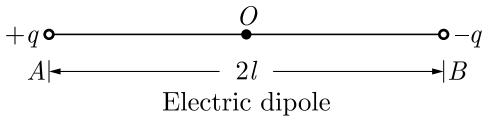


$$|\vec{F}| = \vec{E}(qE - qE) = 0$$

67. Define electric dipole moment and write its SI unit.

Ans : **Main 2012**

The strength of an electric dipole is measure by a vector quantity known as electric dipole moment p which is the product of the charge q and separation between the charges $2l$.



Electric dipole

i.e., $p = q \times 2l$

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or $|p| = q(2l)$

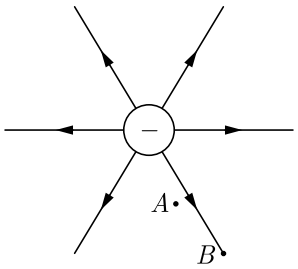
It is a vector quantity and its direction is always from negative charge to positive charge. The SI unit of dipole moment is coulomb-metre (C-m).

68. What do you mean by permittivity of a medium?

Ans : **Main 2008**

Permittivity is a property of the medium which determines the electric force between two charges situated in that medium. For example, the force between two charges located some distance apart in water is about 1/80th of the force between them when they are separated by same distance in air. This is because the permittivity of water is about 80 times greater than the permittivity of air.

69. Figure shows the field lines due to a negative point charge. Give the sign of the potential energy difference of a small negative charge between the point A and B .



Ans : **Main 2015**

As we know that

$$u = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{r}$$

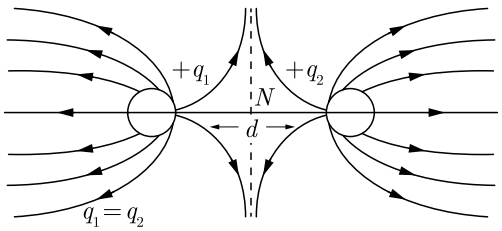
Here, $U_A > U_B$

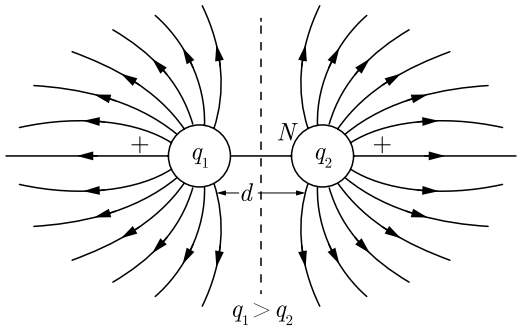
Therefore, $U_A - U_B$ is positive.

70. Sketch the electric field lines for two point charges q_1 and q_2 for $q_1 = q_2$ and $q_1 > q_2$ separated by a distance d.

Ans : **SQP 2013, 2009**

When the charges are equal, the neutral point N lies at the centre of the joining the charges. However, when the charges are unequal, the point N is closer to the smaller charge.





TWO MARKS QUESTIONS

71. What is the electric flux through a cube of side 1 cm which encloses an electric dipole?

Ans : **Comp 2011**

Net electric flux is zero.

Reason :

1. Independent to the shape and size.
2. Net charge of the electric dipole is zero.

72. Explain why two field lines never cross each other at any point.

Ans : **Main 2010**

Two electric lines of force can never cross each other because if they cross, there will be two directions of electric field at the point of intersection (say A); which is impossible.

73. Define electric flux. Write its SI unit.

Ans :

Electric Flux over an area in an electric field represents the total number of electric field lines crossing this area and is given by the product of surface area and the component of electric field intensity normal to the area. The SI unit of flux is NM^2C^{-2}.

74. Define electric dipole moment. Is it a scalar or a vector?

Ans : **SQP 2013**

The strength of an electric dipole is measured by the quantity electric dipole moment. Its magnitude is equal to the product of the magnitude of either charge and the distance between the two charges.

Electric dipole moment,

$$p = q \times d$$

It is a vector quantity.

NODIA

75. Give the physical significance of electric dipoles.

Ans : **Main 2013**

Electric dipoles have a common occurrence in nature. A molecule consisting of positive and negative ions is an electric dipole. Moreover, a complicated array of charges can be described and analysed in terms of electric dipoles. The concept of electric dipole is used

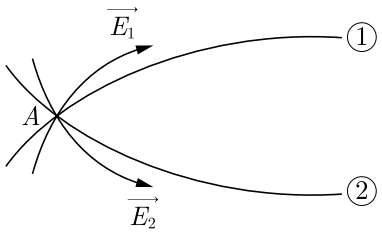
1. In the study of the effect of electric field on an insulator, and
2. In the study of radiation of energy from an antenna.

76. An electrostatic field line is a continuous curve. That is a field line cannot have sudden breaks. Why is it so?

Ans : **Main 2024, 2017**

An electrostatic field line is the path of movement of a positive test charge $(q_0 \to 0)$.

A moving charge experiences a continuous force in an electrostatic field, so an electrostatic field line is always a continuous curve.



77. Define dielectric strength and relative permittivity.

Ans : **Main 2016**

1. **Dielectric Strength :** The maximum electric field that can exist in a dielectric without causing the breakdown of its insulating property is called dielectric strength of the material.
2. **Relative Permittivity :** The dielectric constant or relative permittivity of medium may be defined as the ratio of the force between two charged placed some distance apart in free space to the force between the same two charges when they are placed the same distance apart in the given medium. It is given by,

$$\text{Relative permittivity, } \varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$$

78. A comb after passing through dry hair attracts small pieces of paper. What happens if the hair is wet or if it is a rainy day?

Ans : **SQP 2016, Main 2013**

A dry comb when passed through hair gets charged due to friction and because of this it induces an opposite charge on the paper. The electrostatic force of attraction between the comb and the paper is much greater than the weight of paper therefore it is lifted.

On a wet day, the hair is wet, the friction is quite less and hence, comb does not get charged.

79. Two metallic spheres of exactly equal masses are taken. One is given a positive charge q coulomb and the other an equal negative charge by friction. Art their masses after charging equal?

Ans : **Main 2014**

No, Because when two bodies are rubbed together, there is transfer of electrons from one body to another. Since electrons are material particles, so their transfer from one body to another causes a change in mass. The body from which electrons are removed becomes positively charged and body to which electrons get transferred becomes negatively charged. Hence the mass of negatively charged body will be more than positively charged body.

80. Give the physical significance of electric field.

Ans : **Comp 2021, 2015**

By knowing electric field at any point, we can determine the force on a charge placed at that point. The Coulomb force on a charge q_0 due to a source charge q may be treated as two stage process:

1. The source charge q produces a definite field $\vec{E}(r)$ at every point $\vec{r}$.
2. The value of $\vec{E}(r)$ at any point $\vec{r}$ determines the force on charge q_0 at that point. This force is,

$$\vec{F} = q_0 \vec{E}(r)$$

i.e., Electrostatic force = Charge $\times$ Electric field. Thus an electric field plays an intermediary role in the forces between two charges:

$$\text{Charge} \rightleftharpoons \text{Electric field} \rightleftharpoons \text{Charge}$$

81. What is electrostatic shielding? Give one of its practical applications.

Ans : **Main 2014**

The phenomena of protecting certain region of space from electric field is called electrostatic shielding.

It is based on the fact that electric field vanishes inside the cavity of a hollow conductor.

NODIA

Application of Electrostatic Shielding :

In a thunderstorm accompanied by lighting, it is safest to sit inside a car, rather than near a tree or on the open ground. The metallic body of the car becomes an electrostatic shielding from lighting.

82. Write two basic properties of electric charge.

Ans : **SQP 2012, 2010**

Two properties of electric charge are as follows :

1. **Quantisation of Charge :** The total charge on a body is integral multiple of fundamental charge of electron e.

$$q = \pm ne$$

where, n = is an integer

$$(n = 1, 2, 3.....)$$

2. Like charges repel while unlike charges attract each other.

83. State and explain the superposition principle for electric fields?

Ans : **SQP 2007**

The electric intensity at a point due to several charges is the vector sum of electric intensities produced by each charge individually in the absence of other charge.

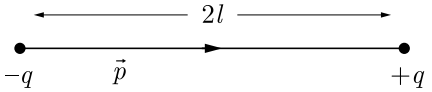
Let the electric field intensities due to individual charges are $\vec{E}_1$, $\vec{E}_2$, $\vec{E}_3$ ..... $\vec{E}_n$ respectively, than resultant electric field intensity is given by,

$$\vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + ...\vec{E}_n$$

84. Define electric dipole moment. Is it a scalar or a vector quantity? What are its SI unit?

Ans : **Comp 2025**

The electric dipole moment is defined as the product of either charge and the distance between the two charges. Its direction is from negative to positive charge.



i.e., $|p| = q(2l)$

85. Two point charges q_1 and q_2 are located at points $(a,0,0)$ and $(0,b,0)$ respectively. Find the electric field due to both these charges at the point $(0,0,c)$?

Ans : **Main 2012**

We have, $\vec{E}_{net} = \vec{E}_1 + \vec{E}_2$

$$= \frac{1}{4\pi\varepsilon_0}\frac{q_1}{r_1^3}\vec{r}_1 + \frac{1}{4\pi\varepsilon_0}\frac{q_2}{r_1^3}\vec{r}_2$$

where $\vec{r}_1 = -a\hat{i} + c\hat{k}$

and $\vec{r}_2 = -b\hat{j} + c\hat{k}$

$$\vec{E}_{net} = \frac{1}{4\pi\varepsilon_0}\left[\frac{q_1(-a\hat{i} + c\hat{k})}{(a^2 + c^2)^{3/2}} + \frac{q_2(b\hat{j} + c\hat{k})}{(b^2 + c^2)^{3/2}}\right]$$

86. A thin straight infinitely long conducting wire having charge density λ is enclosed by a cylindrical surface of radius r and length l, its axis coinciding with the length of the wires. Find the expression for the electric flux through the surface of the cylinder.

Ans : **SQP 2011**

Charge enclosed by the cylindrical surface $= \lambda l$

By Gauss theorem,

$$\text{Electric flux} = \frac{1}{\varepsilon_0} \times \text{charge enclosed}$$

$$= \frac{1}{\varepsilon_0}(\lambda l)$$

87. Two equal balls having equal positive charge q coulombs are suspended by two insulating strings of equal length. What would be the effect on the force when a plastic sheet is inserted between the two?

Ans : **Main 2025, 2020**

Form Coulomb's law, electric force between the two charged bodies, in a medium,

$$F = \frac{1}{4\pi\varepsilon_0 K}\frac{|q_1 q_2|}{r^2}$$

Where, K = dielectric constant of the medium.

For vacuum, $K = 1$

For plastic, $K > 1$

Therefore, after insertion of plastic sheet, the force between the two balls will reduce.

88. Compare the electric fields due to a monopole (single charge) and dipole.

Ans : **SQP 2005, 2010**

The comparison of electric fields due to a monopole and dipole are as follows :

	Electric Monopole	**Electric Dipole**
1.	It is due to charge where value is not zero.	Net charge is zero.
2.	$E \propto \frac{1}{r^2}$	$E \propto \frac{1}{r^3}$
3.	Electric field is spherically symmetric..	Electric field is not spherically symmetric.

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89. Define electric field intensity in current carrying conductor.

Ans : **SQP 2013**

The electric field intensity at any point due to source charge is defined as the force experienced per unit positive charge placed at that point without disturbing the source charge.

$$\vec{E} = \frac{\vec{F}}{q_0}$$

Where, $\vec{E}$ = Electric field intensity

and $\vec{F}$ = Force experienced by the test charge q_0

90. A Gaussian surface contains three charges $(-q)$, $(+2q)$ and $(-q)$. Evaluate net electric flux through the surface.

Ans : **Main 2018**

Total charge in Gaussian surface

$$q = q_1 + q_2 + q_3$$

Here, $q_1 = -q$

$q_2 = +2q$

$q_3 = -q$

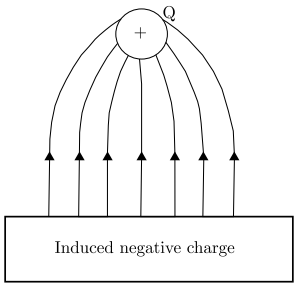
$= -q + 2q - q = 0$

Net flux, $\phi = \frac{q}{\varepsilon_0} = \frac{0}{\varepsilon_0} = 0$

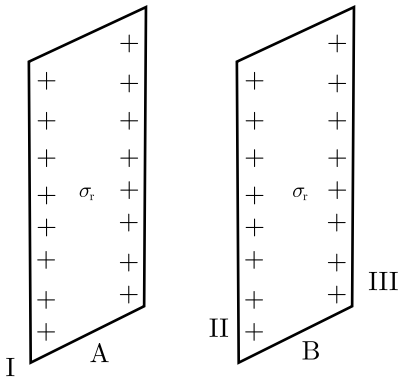
91. A point charge $(+Q)$ is kept in the vicinity of uncharged conducting plate. Sketch electric field lines between the charge and the plate.

Ans : **SQP 2014**

The lines of force start from $+Q$ and terminate at metal place inducing negative charge on it. The lines of force will be perpendicular to the metal surface as shown in figure.



92. Two infinitely large plane thin parallel sheets having surface charge densities σ_1 and σ_2 $(\sigma_1 > \sigma_2)$ are shown in the figure.



Write the magnitudes and directions of the net fields in the regions marked II and III.

Ans : **Main 2010**

(i) Net electric field in regions II

$$= \frac{1}{2\varepsilon_0}(\sigma_1 - \sigma_2)$$

Direction of electric field is from sheet A to sheet B.

(ii) Net electric field in region III

$$= \frac{1}{2\varepsilon_0}(\sigma_1 + \sigma_2)$$

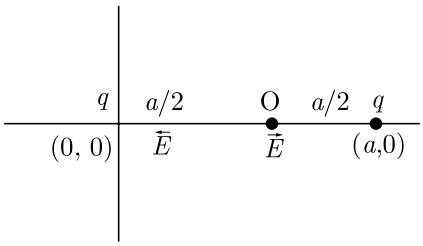
93. Consider two identical point charges (b) located at points (0, 0) and (a, 0).

(i) Is there a point on the line joining them at which the electric field is zero.

(ii) Is there a point on the line joining them at which the electric potential is zero? Justify your answer for each case.

Ans : **SQP 2015**

If at a point electric field due to two charges are equal and opposite, then electric field at that point is zero.



Now, here both charges are equal or identical, then magnitude of the electric field at the mid-point of the line joining the charges is the same but opposite.

So, they will cancel out each other and the net electric field is zero.

NODIA

94. Two identical spheres with charges $4q$, $-2q$ are kept at some distance apart, exert a force F on each other. If they are made to touch each other and replaced at their old positions, then what will be the new force between them?

Ans : **Main 2015**

When two similar bodies having different charges touched together and separated, according to conservation of charge and redistribution of charge they possesses equal amount of charge. When spheres are touched and separated, then charge is,

$$q' = \frac{4q-2q}{2} = \frac{2q}{2} = q$$

From Coulomb's law,

$$F = \frac{1}{4\pi\varepsilon_0}\frac{(4q)(-2q)}{r} \quad ...(1)$$

When made to touched,

$$F' = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{r} \quad ...(2)$$

From Eqs. (1) and (2), we get

$$F' = \frac{F}{8}$$

95. Write down unit and dimension of permittivity of free space.

Ans : **Main 2018**

According to the Coulomb's Law,

$$F = \frac{q_1 q_2}{4\pi\varepsilon_0 r^2}$$

Hence, Permittivity

$$\varepsilon_0 = \frac{q_1 q_2}{4\pi F r^2}$$

$$= \frac{(\text{Coulomb})^2}{\text{Newton-(meter)}^2}$$

Here, $q = [AT]$

$F = [\mathrm{M^1L^1T^{-2}}]$

$r = [L]$

Hence, $\varepsilon_0 = \dfrac{[AT][AT]}{[M^1L^1T^{-2}][L]^2}$

$= [\mathrm{M^{-1}L^{-3}T^4A^2}]$

96. State the law of conservation of charge. Give two examples to illustrate it.

Ans : **Main 2014, 2008**

Law of Conservation of Charge

This law can be stated in a number of ways:

1. The total charge of an isolated system remains constant.
2. The electric charges can neither be created nor destroyed, they can only be transferred from one body to another.

Examples

1. Charge s conserved during the fission of a nucleus by a neutron.

   $${}^1_0\mathrm{n} + {}^{235}_{92}\mathrm{U} \longrightarrow {}^{141}_{56}\mathrm{Ba} + {}^{92}_{36}\mathrm{Kr} + 3{}^1_0\mathrm{n} + \text{Energy}$$

   Total charge before fission $(0+92)$ = Total charge after fission $(56+36+3\times 0)$

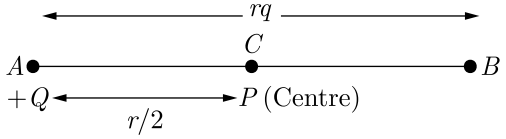
2. Electric charge is conserved during the phenomenon of pair production in which a γ-ray photon materialises into an electron-positron pair.

   $$\underset{\text{zero charge}}{\gamma - \text{ray}} \longrightarrow \underset{(-e)}{\text{electron}} + \underset{(+e)}{\text{positron}}.$$

97. A charge q is placed at the centre of the line joining two equal point charges each equal to Q. If the system of three charges will be in equilibrium, then what should be the value of q ?

Ans : **Main 2010**

To be the system of charges in equilibrium, force between the charge at A and B should be equal to force between the charge at A and C or B and C. For equilibrium of system of charges (i.e. net force on the system = 0).



Now, sum of forces produced between the charges

$$\frac{1}{4\pi\varepsilon_0}\frac{qQ}{\left(\frac{r}{2}\right)^2} + \frac{1}{4\pi\varepsilon_0}\frac{QQ}{r^2} = 0$$

$$\frac{4qQ}{r^2} + \frac{QQ}{r^2} = 0$$

$$q = -\frac{Q}{4}$$

98. Two small, identical in size, charged metallic spheres A and B repel each other with a force F when placed at a distance r between their centres. The spheres A and B are touched by identical, but uncharged spheres C and D, respectively which are then removed away. The sphere B is now brought closer to A to a distance $r/2$ between their centres. What is the new force of repulsion between A and B ?

Ans : **SQP 2008**

Let q_1 and q_2 be the initial charges on spheres A and B, respectively. Then, by Coulomb's law, we have

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

when an identical uncharged sphere C touches A, the charges redistribute on A and C and by symmetry, each acquires a charge $q_1/2$. Similarly,

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when D touches B, each acquires a charge $q_2/2$. If now the distance between A and B is halved, the new force of repulsion is given by

$$F' = \frac{1}{4\pi\varepsilon_0}\frac{(q_1/2)(q_2/2)}{(r/2)^2}$$
$$= \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2} = F$$

The new force of repulsion is same as the initial force of repulsion.

99. Two charged conducting spheres of radii a and b are connected to each other by a wire. Find the ratio of the electric fields at their surfaces.

Ans : **SQP 2023**

Let q_1 and q_2 be the charges C_1 and C_2 be the capacitance of two spheres. The charge flows from the sphere at higher potential to the other at lower potential, till their potentials become equal. After sharing, the charges on two spheres will be

$$\frac{q_1}{q_2} = \frac{C_1 V}{C_2 V} \quad ...(1)$$

Also $$\frac{C_1}{C_2} = \frac{a}{b} \quad ...(2)$$

Then, ratio of surface charge on the two spheres

$$\frac{\sigma_1}{\sigma_2} = \frac{q_1}{4\pi a^2} \times \frac{4\pi b^2}{q_2} = \frac{q_1}{q_2}.\frac{b^2}{a^2}$$
$$= \frac{a}{b}.\frac{b^2}{a^2} \quad \text{[From Eqs. (1) and (2)]}$$
$$= \frac{b}{a}$$

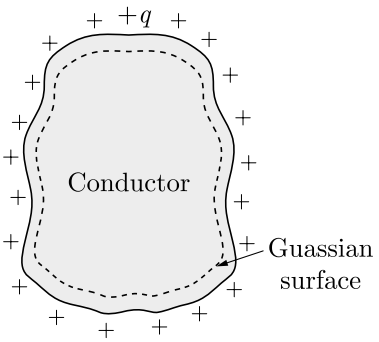
The, ratio of electric fields at the surfaces of two spheres $\frac{E_1}{E_2} = \frac{\sigma_1}{\sigma_2} = \frac{b}{a}$.

100. Show that charge always resides on the outer surface of a conductor.

Ans : **Comp 2007, 2003**

Consider a conductor of any shape or size, which is given a +ve charge $+q$. Consider a Gaussian closed surface just inside the outer surface of the conductor as shown in the figure by dotted lines.

From Gauss's theorem,



$$\oint \vec{E} \cdot \vec{ds} = q/\varepsilon_0$$

But, $\vec{E} = 0$ inside the conductor

$$q = 0$$

i.e., charge inside the conductor is zero, Hence we find that charge always resides on the outer surface of the conductor.

THREE MARKS QUESTIONS

101. Why should electrostatic field be zero inside a conductor?

Ans : **Main 2015**

Charge on conductor resides on its surface. So if we consider a Gaussian surface inside the conductor to find the electrostatic field.

$$\phi = \frac{q}{\varepsilon_0}$$

Where, q= charge enclosed in Gaussian surface.

Hence $q = 0$,

Inside the conductor, hence the electrostatic field inside the conductor is zero.

$$\phi = \oint \vec{E} \cdot \vec{ds} = \frac{q}{\varepsilon_0}$$

$$\oint E \cdot ds \cos\theta = \frac{q}{\varepsilon_0}$$

102. What is the nature of electrostatic force between two point electric charges q_1 and q_2 if

1. $q_1 + q_2 > 0$?
2. $q_1 + q_2 < 0$?

Ans : **SQP 2010**

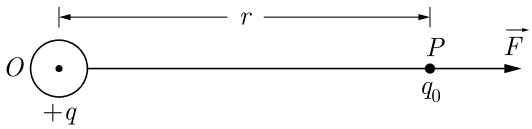
1. If both q_1 and q_2 are positive, the electrostatic force between these will be repulsive.
   However, if one of these charges is positive and is greater than the other negative charge, the electrostatic force between them will be attractive.
   Thus, the nature of force between them can be repulsive or attractive.
2. If both q_1 and q_2 are negative, the force between these will be repulsive.
   However, if one of them is negative and it is greater than the second positive charge, the force between them will be attractive.
   Thus, the nature of force between them can be repulsive or attractive.

NODIA

103. Derive the expression for electric field intensity at a point due to a point charge.

Ans : **Main 2014, 2011**

Suppose we have to calculate electric field intensity at any point P due to a point charge q at O, where $OP = r$. Imagine a positive test charge q_0 at P. According to Coulomb's law, force at P is



$$\vec{F} = \frac{1}{4\pi\varepsilon_0}\frac{qq_0}{r^2}\hat{r}$$

Where, $\hat{r}$ is unit vector directed from q towards q_0

As, $$\vec{E} = \frac{\vec{F}}{q_0}$$

Hence, $$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}$$

$\hat{r}$ is the unit vector in the direction of force.

If q is $+$ve, the field intensity is directed radially outwards along OP. If q is negative, the field intensity is directed towards q, along PO.

104. An electric dipole is placed in a uniform electric field E with its dipole moment p parallel to the field. Find:

1. The work done in turning the dipole till its dipole moment points in the direction opposite to E.
2. The orientation of the dipole for which the torque acting on it becomes maximum.

Ans : **Main 2024**

1. $$W = \int_{\theta_1}^{\theta_2} \tau\, d\theta$$
$$= \int_0^{\pi} pE\sin\theta\, d\theta$$
$$= pE[-\cos\theta]_0^{\pi}$$
$$= 2pE$$

2. $$\tau = pE\sin\theta$$

If, $\theta = \frac{\pi}{2}$, then τ is maximum.

i.e., $$r = pE\sin\frac{\pi}{2}$$
$$\tau = pE \text{ (Maximum)}$$

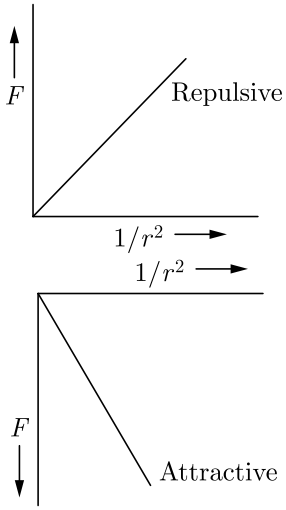
105. Plot a graph showing the variation of Coulomb force F, versus $(1/r^2)$, where r is the distance between the two charges of each pair of charges $(1\propto\text{C}, 2\propto\text{C})$ and $(2\mu\text{C}, -3\mu\text{C})$. Interpret the graphs obtained.

Ans : **SQP 2014**

According to the coulombs law,

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

The graph between F and $1/r^2$ is a straight line of slope $\frac{1}{4\pi\varepsilon_0}q_1 q_2$ passing through origin in both the cases.



Since, magnitude of the slope is more for attraction, therefore, attractive force is greater than repulsive force.

106. Compare the properties of electric charge and mass which are not similar.

Ans : **Main 2025, 2018**

The difference between electric charge and mass are as follows :

	Electric Charge	**Mass**
1.	Electric charge can be $+$ve, $-$ve or zero.	Strictly positive.
2.	Electric charge is always quantised i.e. the charge in a given body is always an integral multiple of a minimum value e, i.e. $q = \pm ne$.	Quantisation of mass is not so clear.

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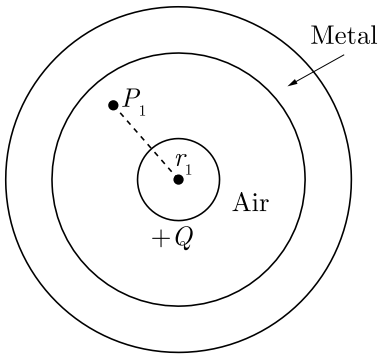
	Electric Charge	Mass
3.	Electric charge is invariant with respect to speed.	Mass increases with speed.
4.	Strictly conserved.	The phenomenon is more apparent at high speeds.
5.	A charge always possesses non-zero mass.	Not conserved by itself in relativistic process. A mass may have non-zero charge.

107. A small metal sphere carrying a charge $+Q$ is located at the centre of a spherical cavity in a large uncharged metallic spherical shell. Write the charges on the inner and outer surfaces of the shell. Write the expression for the electric field at the point P_1.



Ans : **Main 2024, 2015**

The charge on inner surface $= -Q$

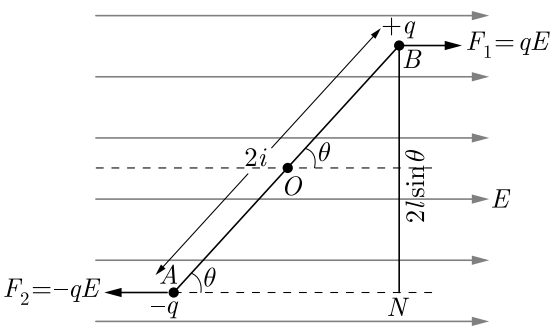
Charge on other surface $= +Q$

Electric field at point P_1 is given by

$$E = \frac{Q}{4\pi\varepsilon_0 r_1^2}$$

108. Derive an expression for the torque experienced by electric dipole in external electric field.

Ans : **SQP 2010**



The forces $\vec{F}_1$ and $\vec{F}_2$ from a couple (or torque) which tends to rotate and align the dipole along the direction of electric field. This couple is called the torque and is denoted by τ.

Hence, Torque

τ = Magnitude of one force $\times$ perpendicular distance between lines of action of forces

$= qE(BN) = qE(2l\sin\theta)$

$= (q\,2l)\,E\sin\theta$

$= pE\sin\theta$ [using (1)] ...(2)

Clearly, the magnitude of torque depends on orientation (θ) of the electric dipole relative to electric field. Torque (τ) is a vector quantity whose direction is perpendicular to the plane containing given by right hand screw rule $\vec{p}$ and $\vec{E}$.

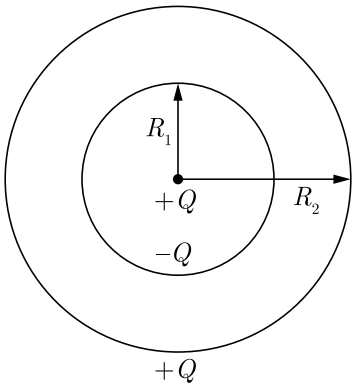
In vector form, $\vec{\tau} = \vec{p} \times \vec{E}$

109. A metallic spherical shell has an inner radius R_1 and outer radius R_2. A charge Q is placed at the centre of the spherical cavity. What will be surface charge density on

1. The inner surface
2. The outer surface?

Ans : **Comp 2006**

When a charge $+Q$ is placed at the centre of spherical cavity,



The charge induced on the inner surface $= -Q$

The charge induced on the outer surface $= +Q$

Surface charge density on the inner surface

$$= \frac{-Q}{4\pi R_1^2}.$$

Surface charge density on the outer surface

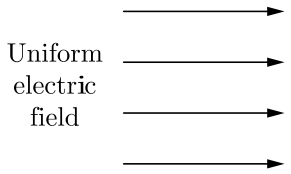
$$= \frac{+Q}{4\pi R_2^2}.$$

NODIA

110. Define uniform and non-uniform electric fields. How are they represented geometrically?

Ans : **Main 2009, 2014**

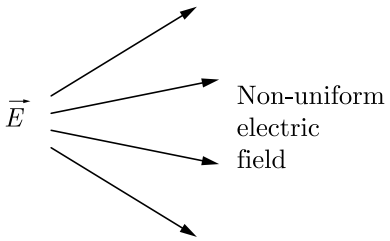
A uniform electric field has same intensity (both in magnitude and direction) at all points in it. Therefore, the electric field vectors at all the points must be of the same length and point in the same direction. Hence a uniform field is represented by a set of parallel lines pointing in the same direction.



(a)

A non-uniform field is that in which electric intensity is different at different parts, either in magnitude or direction or both.

A uniform and a non-uniform electric field are represented by the lines of force as shown in Figures (a) and (b) respectively.

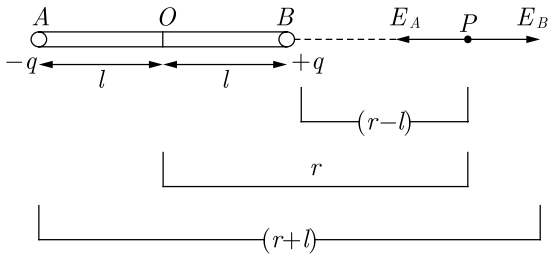


(b)

111. Obtain an expression for intensity of electric field at a point in end-on-position, i.e. axial position of an electric dipole.

Ans : **Main 2025, 2018**

We have to calculate the field (E) at a point P on the axial line of the dipole and at a distance $OP = r$ from the centre O of the dipole.



The vectors $\vec{E}_A$ and $\vec{E}_B$ are collinear and opposite, so, resultant electric field intensity at the point P,

$$|E_P| = |E_B - E_A|$$

Here, $$|E_A| = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{(r+l)^2}$$

and $$|E_B| = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{(r-l)^2}$$

$$E_P = \frac{1}{4\pi\varepsilon_0}\left[\frac{q}{(r-l)^2} - \frac{q}{(r+l)^2}\right]$$

But $$|\vec{p}| = q \times 2l$$

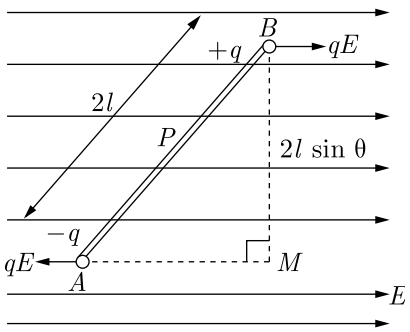
$$E_p = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2pr}{(r^2-l^2)^2}$$

112. An electric dipole is placed in a uniform external electric field $\vec{E}$. Show that the torque acting on the dipole is given by $\tau = \vec{p} \times \vec{E}$, where $\vec{p}$ is the dipole moment.

Ans : **Main 2005**

We can find torque by multiplying magnitude of either force by perpendicular distance between the forces.

The dipole shown in the diagram is placed in a uniform electric field $\vec{E}$. The direction of electric dipole moment $\vec{p}$ makes an angle θ with electric field. The forces in a pair are acting on the dipole as shown in the figure.



By definition, Torque

(τ) = Magnitude of either force

$\times$ Perpendicular distance between the forces

$= qE \times BM = qE \times 2l\sin\theta$

$= 2qlE\sin\theta = pE\sin\theta$

$\tau = \vec{p} \times \vec{E}$

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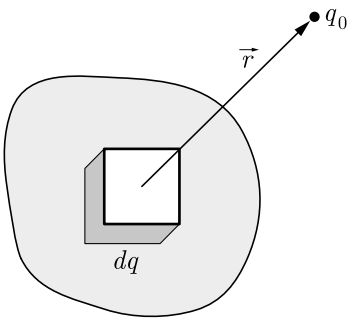
113. What is a continuous charge distribution? How can we calculate the force on a point charge q due to a continuous charge distribution?

Ans : **SQP 2019, 2017**

When the charge involved is much greater than the charge on an electron, we can ignore its quantum nature and assume that the charge is distributed in a continuous manner. This is known as a continuous charge distribution.

Force on a point charge due to a continuous charge distribution. As shown in consider a point charge q_0 lying near a region of continuous charge distribution. This continuous charge distribution can be imagined to consist of a large number of small charges dq. According to Coulomb's law, the force on point charge q_0 due to small charge dq is



Force on a point Charge q_0 due to a continuous charge distribution,

$$d\vec{F} = \frac{1}{4\pi\varepsilon_0}\frac{q_0\,dq}{r^2}\cdot\hat{r}$$

Where, $\hat{r} = \vec{r}/r$, is a unit vector pointing from the small charge dq towards the point charge q_0. By the principle of superposition, the total force on charge q_0 will be the vector sum of the forces exerted by all such small charges and is given by

$$\vec{F} = \int d\vec{F} = \int \frac{1}{4\pi\varepsilon_0}\cdot\frac{q_0\,dq}{r^2}\cdot\hat{r}$$

$$= \frac{q_0}{4\pi\varepsilon_0}\int \frac{dq}{r^2}\cdot\hat{r}$$

114. (i) Write an expression (derivation not required) for intensity of electric field in

(a) axial position.

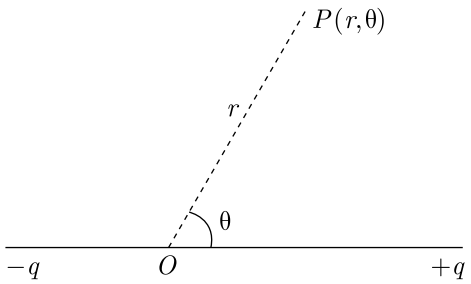
(b) broadside position of an electric dipole, in terms of its length $(2a)$ dipole moment (p) and distance (r).

(ii) What is the ratio of these two intensities i.e. $E_1 : E_2$, for a short electric dipole?

Ans : **Main 2013**

(i) Electric field at a general point $P(r,\theta)$ due to dipole is given by

$$E = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3}\sqrt{3\cos^2\theta + 1}$$



(a) For axial position $\theta = 0^\circ$,

$$E_a = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3}\times 2 = \frac{1}{4\pi\varepsilon_0}\frac{2p}{r^3}$$

(b) For broadside on position $\theta = 90^\circ$

$$E_b = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3}\times 1 = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3}$$

(ii) The ratio of $\vec{E}$ at axial and broad on positions is given by

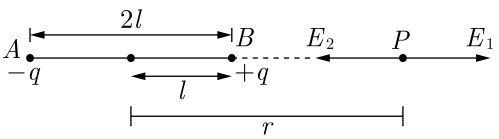
$$\frac{E_a}{E_b} = \frac{\frac{1}{4\pi\varepsilon_0}\left(\frac{2p}{r^3}\right)}{\frac{1}{4\pi\varepsilon_0}\left(\frac{p}{r^3}\right)} = \frac{2}{1}$$

$$E_a : E_b = 2:1$$

115. Obtain an expression for intensity of electric field at a point in end on position i.e. on an axial line of an electric dipole.

Ans : **SQP 2023**

Consider a dipole AB made up of two charges $-q$ and $+q$ separated by a distance $2l$. Let P be any point on the axis at a distance r from the mid-point O of the dipole. We have to determine electric field intensity at the point P.



$$\vec{E}_1 = \frac{1}{4\pi\varepsilon_0}\frac{q}{(r-l)^2}$$

[along the direction of dipole]

$$\vec{E}_2 = \frac{1}{4\pi\varepsilon_0}\frac{q}{(r+l)^2}$$

[opposite the direction of dipole]

The resultant electric field intensity $\vec{E}$ at P is

$$E_{\text{net}} = \vec{E}_1 - \vec{E}_2 \qquad [\text{as } E_1 > E_2]$$

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$$= \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{(r-l)^2} - \frac{1}{(r+l)^2}\right]$$

$$= \frac{q}{4\pi\varepsilon_0}\left[\frac{(r+l)^2-(r-l)^2}{(r-l)^2(r+l)^2}\right]$$

$$= \frac{q}{4\pi\varepsilon_0}\left[\frac{2l\times 2r}{(r^2-l^2)^2}\right]$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{2ql\times 2r}{(r^2-l^2)^2} \quad [\text{where, } p = 2ql]$$

$$\vec{E}_{\text{net}} = \frac{1}{4\pi\varepsilon_0}\frac{2pr}{(r^2-l^2)^2}$$

As $(l <<< r)$

So, $(r^2-l^2)^2 \approx (r^2)^2$,

$$\vec{E}_{\text{net}} = \frac{1}{4\pi\varepsilon_0}\frac{2pr}{r^4}$$

$$\vec{E}_{\text{net}} = \frac{1}{4\pi\varepsilon_0}\frac{2p}{r^3}$$

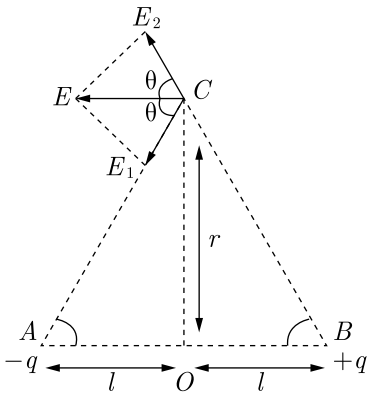
116. Show that intensity of electric field $\vec{E}$ at a point in broadside on position is given by

$$E = \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{p}{(r^2+l^2)^{3/2}}$$

where the terms have their usual meanings.

Ans : **Main 2020, 2018**

Consider an electric dipole, consisting of two point charges $-q$ and $+q$, separated by a small distance $AB = 2l$, with centre at O.



So, dipole moment, $\vec{p}\,| = q(2l)$

Let $OC = r$

Here, E_1 = Electric intensity at C due to charge $-q$ at A.

$$E_1 = \frac{1}{4\pi\varepsilon_0}\frac{q}{AC^2}$$

$$AC^2 = OC^2 + AO^2 = r^2 + l^2$$

$$E_1 = \frac{1}{4\pi\varepsilon_0}\frac{q}{(r^2+l^2)}$$

Similarly $E_2 = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2+l^2}$ (due to charge $+q$ at B)

For equatorial point C,

$$\angle CAB = \angle CBA = \theta$$

Hence, the equivalent of E_1 and E_2,

$$\vec{E} = [(-\hat{i}E_1\cos\theta - \hat{j}E_1\sin\theta) + (-)\hat{i}E_2\cos\theta + \hat{j}E_2\sin\theta]$$

$$|\vec{E}| = (-E_1\cos\theta - E_2\cos\theta)\hat{i} \quad [E_1 = E_2]$$

Take only magnitude and remove negative sign

$$E = 2E_1\cos\theta \qquad (E_1 = E_2)$$

$$= \frac{2}{4\pi\varepsilon_0}\frac{q}{(r^2+l^2)}\cos\theta \quad \left(\cos\theta = \frac{l}{\sqrt{r^2+l^2}}\right)$$

$$= \frac{2ql}{4\pi\varepsilon_0(r^2+l^2)^{3/2}}$$

$$= \frac{p}{4\pi\varepsilon_0(r^2+l^2)^{3/2}}$$

$$E = \frac{1}{4\pi\varepsilon_0}\frac{p}{(r^2+l^2)^{3/2}}$$

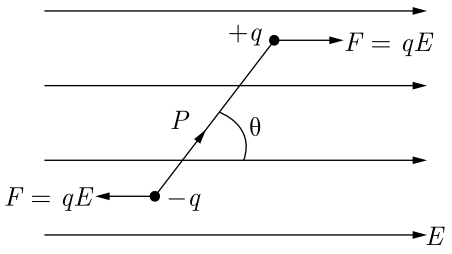
117. An electric dipole of dipole moment $\vec{p}$ is placed in a uniform electric field $\vec{E}$ with its axis inclined to the field. Write an expression for the torque τ experienced by the dipole in vector form. Show diagramatically, show the dipole should be kept in the electric field so that the torque acting on it is

(i) maximum

(ii) zero

Ans : **Main 2025, 2014**

Torque on an electric dipole placed in the uniform electric field $(\vec{E})$

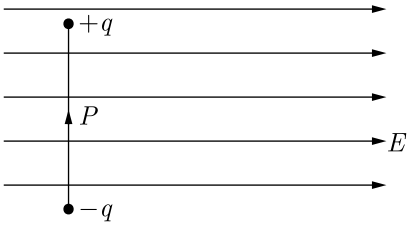


Torque, $\tau = \vec{p}\times\vec{E}$

$$|\tau| = pE\sin\theta$$

$$\tau = pE\sin\theta$$

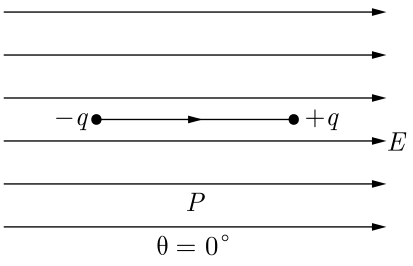
(i) For maximum torque, $\sin\theta = 1$ or $\theta = 90^\circ$

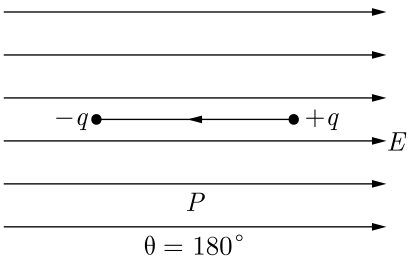


So, dipole should be kept perpendicular to the electric field.

(ii) Minimum torque experienced by electric dipole in electric field, when $\theta = 0^\circ$ or $\pi(180^\circ)$

$$\tau = \tau_{\min} = 0$$

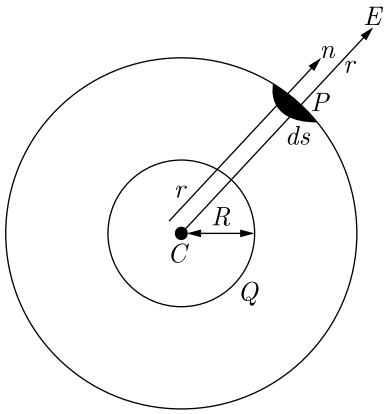




118. Using Gauss' theorem, obtain and expression for intensity of electric field E at a point, which is at a distance $r\,(r > R)$ from the centre C of a thin spherical shell (of radius R) carrying charge Q.

Ans : **SQP 2018**

Consider a shell of radius R with centre C. Let $+Q$ charge in uniformly distributed over the surface of shell, now electric field intensity at point r can be calculated by Gauss' theorem.



So, According to Gauss' theorem

$$\oint_S \vec{E} \cdot d\vec{s} = \oint \vec{E} \cdot \hat{n} ds = \frac{q}{\varepsilon_0}$$

[$\hat{n}$ = unit vector, $\vec{r}$ = position vector along $\vec{E}$]

$$\oint E d\vec{s} \cos 0^\circ = \frac{q}{\varepsilon_0}$$

$$E \oint d\vec{s} = \frac{q}{\varepsilon_0}$$

$$E(4\pi r^2) = \frac{q}{\varepsilon_0} \qquad [\vec{s} = 4\pi r^2]$$

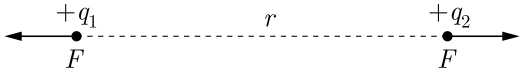
$$E = \frac{q}{4\pi\varepsilon_0 r^2}$$

119. State Coulomb's law. Define Coulomb's dielectric constant.

Ans : **Main 2008, 2005**

The law states that two stationary electric point charges attract or repel each other with a force which is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance between them.

Let q_1, q_2 two point like charges separated by a distance r, then the force between the two charges is



$$F \propto q_1 q_2$$

$$F \propto \frac{1}{r^2}$$

Hence, $$F \propto \frac{q_1 q_2}{r^2}$$

$$F = k\frac{q_1 q_2}{r^2} \qquad ...(1)$$

where k is the constant of proportionality and its value depends upon (1) system of unit adopted and (2) the nature of medium separating q_1 and q_2.

In SI, $k = \frac{1}{4\pi\varepsilon} = \frac{1}{4\pi\varepsilon_0\varepsilon_r}$ [since, $\varepsilon = \varepsilon_0\varepsilon_r$]

where ε is called absolute permittivity, and ε_0 is called permittivity of free space (vacuum) and ε_r is called relative permittivity (or dielectric constant K) of the medium.

The value of $\varepsilon_0 = 8.854 \times 10^{-12} \mathrm{C^2 N^{-1} m^{-2}}$

So, Eq. (1) becomes,

$$F = \frac{1}{4\pi\varepsilon_0\varepsilon_r}\frac{q_1 q_2}{r^2}$$

In vacuum (or in air) $\varepsilon_r = 1$.

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$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

In SI, $$\frac{1}{4\pi\varepsilon_0} = \frac{1}{4 \times 3.142 \times 8.854 \times 10^{-12}}$$

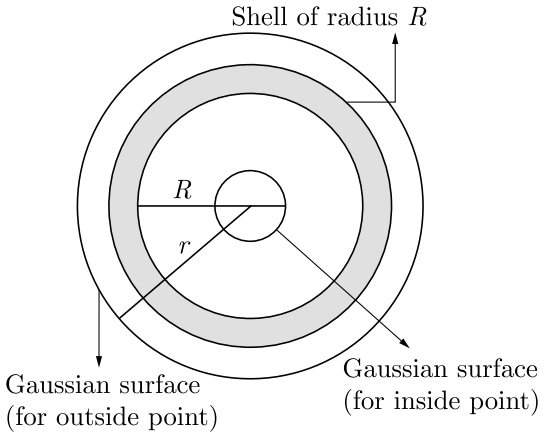
$$= 9 \times 10^9\ \mathrm{Nm^2C^{-2}}$$

$$F = 9 \times 10^9 \frac{q_1 q_2}{r^2}$$

120. Plot a graph showing the variation of Coulomb force (F) versus $1/r^2$, where r is the distance between the two charges of each pair of charges $(1\propto C, 2\propto C)$ and $(1\propto C - 3\propto C)$. Interpret the graphs obtained.

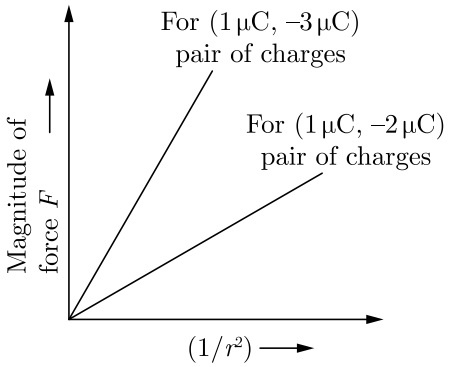
Ans : **SQP 2011**

According to Coulomb's law, the magnitude of force acting between two stationary point charges is given by $F = \left(\frac{q_1 q_2}{4\pi\varepsilon_0}\right)\left(\frac{1}{r^2}\right)$



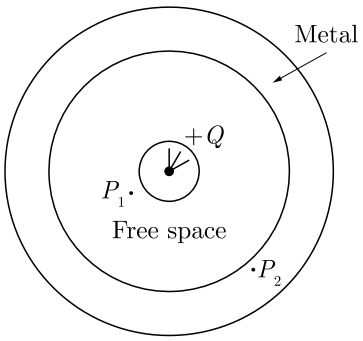
For given $q_1 q_2$ $\quad F \propto \left(\frac{1}{r^2}\right)$

The slope of F versus $1/r^2$ graph depends on $q_1 q_2$.
Magnitude of $q_1 q_2$ is higher for second pair.
Hence Slope of F versus $1/r^2$ graph.



FOUR MARKS QUESTIONS

121. (a) A small metal sphere carrying charge + Q is located at the centre of a spherical cavity inside a large uncharged metallic spherical shell as shown in the figure. Use Gauss's law to find the expressions for the electric field at points P_1 and P_2.



(b) Draw the pattern of electric field lines in this arrangement.

Ans : **SQP 2019, 2007**

(a) Let point P_1 is at distance R from the centre O.
S_1 is the Gaussian surface, then according to Gauss's theorem

$$\oint_S \vec{E}.\overrightarrow{dS} = \oint_S \vec{E}.\hat{n}ds$$

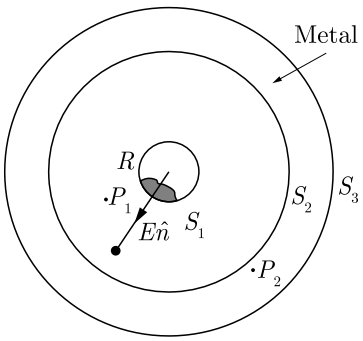
$$= \frac{q}{\varepsilon_0}$$

or $$E\oint_S dS = \frac{q}{\varepsilon_0}$$

$$= \frac{q}{4\pi\varepsilon_0 R^2} \quad \left[\text{As}\oint_S dS = 4\pi r^2\right]$$

Inside the shell the charge is zero, so the field is also zero.

(b)



The direction of electric field is shown in above figure.

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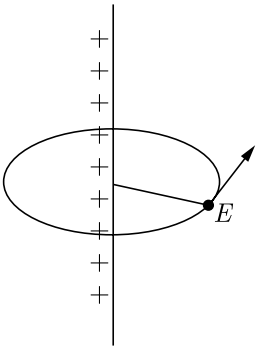
122. An infinitely long positively charged straight wire has a linear charge density λ. An electron is revolving in a circle with a constant speed v such that the wire passes through the centre and is perpendicular to the plane of the circle. Find the kinetic energy of the electron in terms of magnitudes of the charge and linear charge density λ on the wire.

Ans : **SQP 2014**

Infinitely long charged wire produces a radical electric field

$$E = \frac{\lambda}{2\pi\varepsilon_0 l} \quad ...(1)$$

The revolving electron experiences an electrostatic force and provides necessary centripetal force.



$$eE = \frac{mv^2}{r} \quad ...(2)$$

$$\frac{e\lambda}{2\pi\varepsilon_0 r} = \frac{mv^2}{r}$$

$$mv^2 = \frac{e\lambda}{2\pi\varepsilon_0}$$

Kinetic energy of the electron,

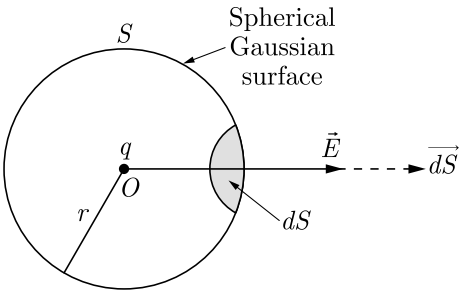
$$K = \frac{1}{2}mv^2$$

$$= \frac{e\lambda}{4\pi\varepsilon_0}$$

123. Deduce Coulomb's law from Gauss law with labelled diagram.

Ans : **Main 2024**

As shown in figure consider an isolated positive point charge q. We select a spherical surface S of radius r centred at charge q as the Gaussian surface.



By symmetry, $\vec{E}$ has same magnitude at all points on S. Also, $\vec{E}$ and $\overrightarrow{dS}$ at any point on S are directed radially outward. Hence, flux through area $\overrightarrow{dS}$ is

$$d\phi_E = \vec{E}.\vec{dS} = EdS\cos 0^\circ = EdS$$

Net flux through closed surface S is,

$$\phi_E = \oint_S \vec{E}.\overrightarrow{dS}s = \oint_S EdS = E\oint_S dS$$

$$= E \times \text{total surface area of } S$$

$$= E \times 4\pi r^2 \quad ...(1)$$

Using Gauss's theorem,

From Eq. (1), we get,

$$\phi_E = \frac{q}{\varepsilon_0}$$

$$E \times 4\pi r^2 = \frac{q}{\varepsilon_0}$$

$$E = \frac{1}{4\pi\varepsilon_0}.\frac{q}{r^2}$$

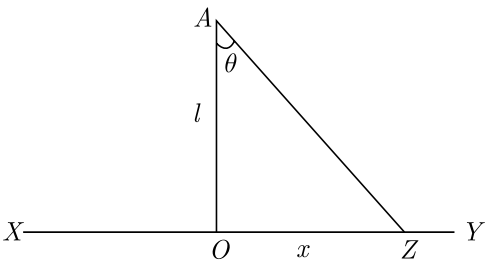
The force on the point charge q_0 if placed on surface S will be,

$$F = q_0 E = \frac{1}{4\pi\varepsilon_0}\frac{qq_0}{r^2}$$

This proves the Coulomb's law.

124. Use Gauss's law to obtain an expression for the electric field due to an infinitely long thin straight wire with uniform linear charge density.

Ans : **Main 2023, 2017**



Take a long thin wire of uniform linear charge density λ.

Consider a point A at a perpendicular distance l from the mid-point O of the wire. Let E be

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the electric field at point A due to the wire XY. Consider a small length element dx on the wire section with $OZ = x$.

Let q be charge on this piece.

$$q \ \lambda.dx$$

Electric field due to the piece ;

$$dE = \frac{1}{4\pi\varepsilon_0 (AZ)^2}$$

$$AZ = \sqrt{l^2 + x^2}$$

$$dE = \frac{\lambda dx}{4\pi\varepsilon_0 (l^2 + x^2)}$$

The electric field is resolved into rectangular components $dE \cos\theta$ and $dE \sin\theta$ when the whole wire is considered the component $dE \sin\theta$ is cancelled.

Only the perpendicular component $dE \cos\theta$ affects points.

Hence, effective electric field at point A due to element dx is dE_1,

$$dE_1 = \frac{\lambda dx \cos x}{4\pi\varepsilon_0 (x^2 + l^2)} \qquad ...(1)$$

In ΔAZO, $\tan\theta = \frac{x}{l}$

$$x = l \tan\theta \qquad ...(2)$$

On differentiating equation (1), we obtain

$$dx = l \sec^2\theta d\theta$$

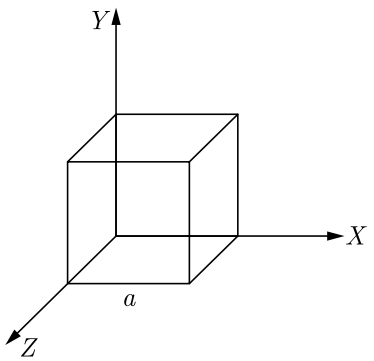
$$dE_1 = \frac{\lambda \cos\theta \, d\theta}{4\pi\varepsilon_0 l}$$

$$E_1 = \oint_{-\pi/2}^{\pi/2} \frac{\lambda \cos\theta \, d\theta}{4\pi\varepsilon_0 l}$$

$$E_1 = \frac{\lambda}{2\pi\varepsilon_0 l}$$

125. Given the electric field in the region $E = 2xi$, find the net electric flux through the cube and the charge enclosed by it.

Ans : **SQP 2009**



Since, the electrical field has only a component, for faces normal to x - direction, the angle between E and ΔS is $\pm\frac{\pi}{2}$.

Therefore, the flux is separately zero for each of the cube. The magnitude of the electric field at the left face is

$$E_l = 0 \qquad (\text{as, } x = 0 \text{ at the left face})$$

The magnitude of the electric field at the right face is

$$E_R = 3a \qquad (\text{as, } x = 0 \text{ at the right face})$$

The corresponding fluxes are

$$\phi_L = \vec{E}_L \cdot \Delta \vec{S} = 0$$

$$\phi_R = \vec{E}_R \cdot \Delta \vec{S}$$

$$= E_R \Delta S \cos\theta$$

$$= E_R \Delta S \qquad (\because \theta = 0^\circ)$$

$$\phi_R = E_R a^2$$

Net flux (ϕ) through the cube

$$= \phi_L + \phi_R$$

$$= 0 + E_R a^2 = E_R a^2$$

$$q = 2a(a)^2 = 2a^3$$

We can use Gauss's law to find the total charge q inside the cube.

$$\phi = \frac{q}{\varepsilon_0}$$

$$= 2a^3/\varepsilon_0$$

126. Derive an expression for intensity of electric field at a point in broadside position or on an equatorial line of an electric dipole.

Ans : **Main 2015, 2013**

Consider an electric dipole AB consists of two charges $+q$ and $-q$ separated by a distance $2a$. We have to find electric field at point P on equatorial line separated by a distance r.

Electric field at point P due to charge $+q$

$$\vec{E}_1 = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{\left(\sqrt{r^2 + a^2}\right)^2}$$

$$= \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{(r^2 + a^2)}, \qquad [\text{along } AP]$$

Electric field at point P due to charge $-q$,

$$\vec{E}_2 = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r^2 + a^2}, \qquad [\text{along } PB]$$

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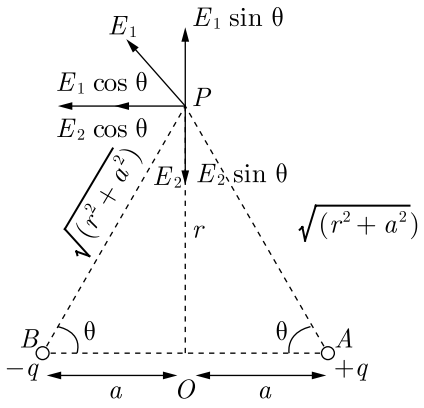


On resolving $\vec{E}_1$ and $\vec{E}_2$, into rectangular components, we get resultant electric field at point P,

$$E = E_1\cos\theta + E_2\cos\theta$$

$$= \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{r^2+a^2}\cos\theta + \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{(r^2+a^2)}\cos\theta$$

$$= 2\times\frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{(r^2+a^2)}\times\frac{a}{\sqrt{r^2+a^2}}$$

$$= \frac{1}{4\pi\varepsilon_0}\cdot\frac{q\,.\,2a}{(r^2+a^2)^{3/2}}$$

But $q\cdot 2a = p$

$$E = -\frac{1}{4\pi\varepsilon_0}\cdot\frac{p}{(r^2+a^2)^{3/2}}$$

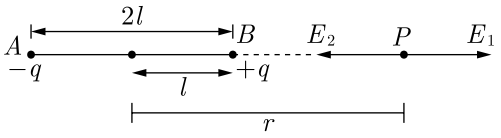
If $r >> a$, then

$$E = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3}$$

127. Obtain an expression for intensity of electric field in end on position, i.e. axial position of an electric dipole.

Ans : **Main 2011**

Consider a dipole AB made up of two charges $-q$ and $+q$ separated by a distance $2l$. Let P be any point on the axis at a distance r from the mid-point O of the dipole. We have to determine electric field intensity at the point P.



$$\vec{E}_1 = \frac{1}{4\pi\varepsilon_0}\frac{q}{(r-l)^2}$$

[along the direction of dipole]

$$\vec{E}_2 = \frac{1}{4\pi\varepsilon_0}\frac{q}{(r+l)^2}$$

[opposite the direction of dipole]

The resultant electric field intensity $\vec{E}$ at P is

$$E_{net} = \vec{E}_1 - \vec{E}_2 \qquad [\text{as } E_1 > E_2]$$

$$= \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{(r-l)^2} - \frac{1}{(r+l)^2}\right]$$

$$= \frac{q}{4\pi\varepsilon_0}\left[\frac{(r+l)^2-(r-l)^2}{(r-l)^2(r+l)^2}\right]$$

$$= \frac{q}{4\pi\varepsilon_0}\left[\frac{2l\times 2r}{(r^2-l^2)^2}\right]$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{2ql\times 2r}{(r^2-l^2)^2} \qquad [\text{where, } p = 2ql]$$

$$\vec{E}_{net} = \frac{1}{4\pi\varepsilon_0}\frac{2pr}{(r^2-l^2)^2}$$

As $(l <<< r)$

So, $(r^2-l^2)^2 \approx (r^2)^2$,

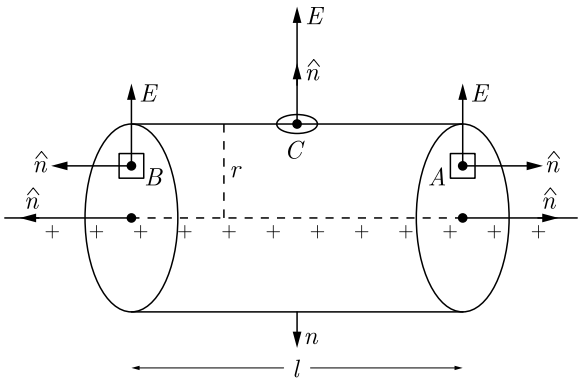
$$\vec{E}_{net} = \frac{1}{4\pi\varepsilon_0}\frac{2pr}{r^4}$$

$$\vec{E}_{net} = \frac{1}{4\pi\varepsilon_0}\frac{2p}{r^3}$$

128. Apply this to obtain the expression for the electric field intensity at a point due to an infinitely long, thin, uniformly charged straight wire.

Ans : **SQP 2016, 2014**

Consider an infinitely long with straight wire with uniform linear charge density λ.



From symmetry, the electric field is everywhere radial in the plane cutting the wire normally and its magnitude only depends on the radial distance r.

From Gauss' law,

$$\phi_E = \oint_S E.dS = \frac{q}{\varepsilon_0}$$

Now, $$\phi_E = \oint_S E.dS = \oint_S E.\hat{n}\,dS$$

$$= \oint_A E.\hat{n}\,dS + \oint_B E.\hat{n}\,dS + \oint_C E.\hat{n}\,dS$$

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Hence, $\oint_S E.dS = \oint_A E\,dS\cos 90^\circ + \oint_B E\,dS\cos 90^\circ + \oint_C E\,dS\cos 0^\circ$

$= \oint_C E\,dS = E(2\pi rl)$

Charge enclosed in the cylinder,

$q = \lambda l$

Hence, $E(2\pi rl) = \frac{\lambda l}{\varepsilon_0}$

or $E = \frac{\lambda}{2\pi\varepsilon_0 r}$

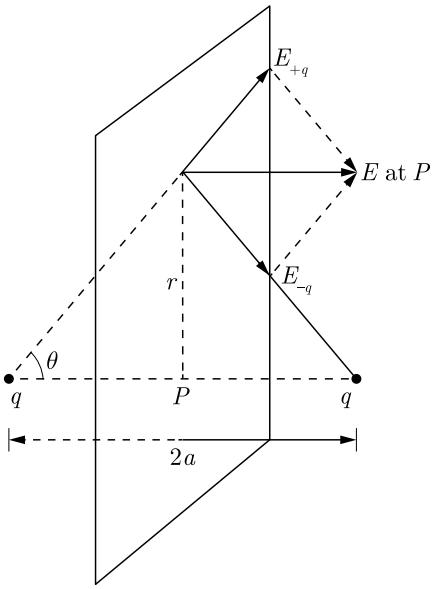
Vectorially, $E = \frac{\lambda}{2\pi\varepsilon_0 r}\hat{r}$

The direction of the electric field is radially outward from the positive line charge. For negative line charge, it will be radially inward.

Thus, electric field E due to the linear charge is inversely proportional to the distance r from the linear charge.

129. Derive the expression for the electric field of a dipole at a point on the equatorial plane of the dipole.

Ans : **Main 2025**



The magnitudes of the electric field due to the two charges $+q$ and $-q$ are given by,

$E_{+q} = \frac{q}{4\pi\varepsilon_0}\cdot\frac{1}{r^2+a^2}$ ...(1)

$E_{-q} = \frac{q}{4\pi\varepsilon_0}\cdot\frac{1}{r^2+a^2}$ ...(2)

Hence, $E_{+q} = E_{-q}$

The direction of E_{+q} and E_{-q} are as shown in the figure.

The components normal to the dipole axis cancel away.

The components along the dipole axis add up.

Hence, Total electric field,

$E = -(E_{+q} - E_{-q})\cos\theta\hat{p}$

[Negative sign shows that field is opposite to $\hat{p}$]

$E = \frac{2qa}{4\pi\varepsilon_0(r^2+a^2)^{3/2}}\hat{p}$ ...(3)

At large distances ($r >> a$), this reduces to

$E = \frac{2qa}{4\pi\varepsilon_0 r^3}\hat{p}$ ...(4)

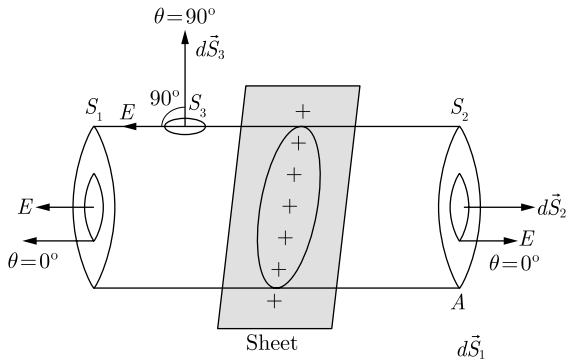
Since, $\vec{p} = q\times 2\vec{a}\hat{p}$

Hence, $E = \frac{-\vec{p}}{4\pi\varepsilon_0 r^3}(r >> a)$

130. Using Gauss's law, prove that the electric field at a point due to a uniformly charged infinite plane sheet is independent of the distance from it.

Ans : **Main 2016, 2012**

Let electric charge be uniformly distributed over the surface of a thin, non-conducting infinite sheet. Let the surface charge density (i.e., charge per unit surface area) be σ. We need to calculate the electric field strength at any point distance r form the sheet of charge.



To calculate the electric field strength near the sheet, we now consider a cylindrical Gaussian surface bounded by two plane faces A and B lying on the opposite sides and parallel to the charged sheet and the cylindrical surface perpendicular to the sheet as shown in the figure. By symmetry the electric field strength at every point on the flat surface is the same and its direction is normal outwards at the points on the two plane surfaces and parallel to the curved surface, $d\vec{S}_1$

Total electric flux,

$\oint_S \vec{E}\cdot d\vec{S} = \oint_{S_1}\vec{E}\cdot d\vec{S}_1 + \oint_{S_2}\vec{E}\cdot d\vec{S}_2 + \oint_{S_3}\vec{E}\cdot d\vec{S}_3$

$\oint_S \vec{E}\cdot d\vec{S} = \int_{S_1} E dS_1\cos 0^\circ + \int_{S_2} E dS_2\cos 0^\circ + \int_{S_3} E dS_3\cos 90^\circ$

$$= E\int dS_1 + E\int dS_2$$
$$= Ea + Ea = 2Ea$$

Hence, Total electric flux $= 2Ea$.

As σ is charge per unit area of sheet and a is the intersecting area, the charge enclosed by Gaussian surface $= \sigma a$.

Now from the Gauss's theorem.

Total electric flux

$$= \frac{1}{\varepsilon_0} \times (\text{total charge enclosed by the surface})$$

i.e., $\quad 2Ea = \frac{1}{\varepsilon_0}(\sigma a)$

Hence, $\quad E = \frac{\sigma}{2\varepsilon_0}$

Thus, electric field strength due to an infinite flat sheet of charge is independent of the distance of the point and is directed normally away from the charge. If the surface charge density σ is negative the electric field is directed towards the surface charge.

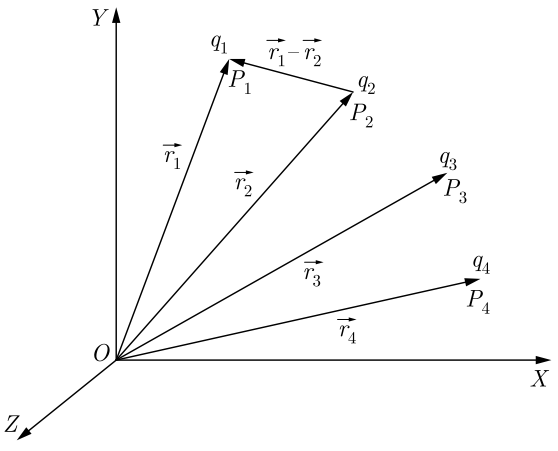
131. State and explain Superposition Principle. Find an expression for the total force acting on a given charge due to a number of other charges, when the source charges are point charges.

Ans : **Comp 2021, 2014**

The resultant electric force at a point charge due to a number of charges in its neighbourhood is the vector sum of the electric forces produced by each charge individually in the absence of other charges.

If a charge q_1 experiences forces $\vec{F}_{12}, \vec{F}_{13} ..... \vec{F}_{1n}$ due to other charge q_2, q_3 ..... respectively then the total force $\vec{F}$ experienced by the charge q_1 is given by,

$$\vec{F} = \vec{F}_{12} + \vec{F}_{13} + ... + \vec{F}_{1n}$$



Suppose we have many point charges q_1, q_2, q_3 ..... at points P_1, P_2, P_3 ..... in space, with position vectors $\vec{r}_1$, $\vec{r}_2$, $\vec{r}_3$, ... The total force $\vec{F}_1$ on charge q_1 is the vector sum of the individual forces that each of the other charges q_2, q_3 ..... exert on it. Therefore, using Coulomb's law of electrostatics

$$\vec{F}_{12} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{|\vec{r}_1 - \vec{r}_2|^3}(\vec{r}_1 - \vec{r}_2)$$

Similarly, force on charge q_1 due to charge q_2

$$\vec{F}_{13} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_3}{|\vec{r}_1 - \vec{r}_3|^3}(\vec{r}_1 - \vec{r}_3)s$$

$$\vec{F}_{1n} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_n}{|\vec{r}_1 - \vec{r}_n|^3}(\vec{r}_1 - \vec{r}_n)s`$$

Hence, total force on charge q_1 due to all other charges

$$\vec{F} = \vec{F}_{12} + \vec{F}_{13} + ... + \vec{F}_{1n}$$

$$= \frac{q_1}{4\pi\varepsilon_0}\left[\frac{q_2}{|\vec{r}_1 - \vec{r}_2|^3}(\vec{r}_1 - \vec{r}_2) + \frac{q_3}{|\vec{r}_1 - \vec{r}_3|^3}(\vec{r}_1 - \vec{r}_3) + ... + \frac{q_n}{|\vec{r}_1 - \vec{r}_n|^3}(\vec{r}_1 - \vec{r}_n)\right]$$

$$= \frac{q_1}{4\pi\varepsilon_0}\sum_{i=1}^{i=n}\frac{q_i}{|\vec{r}_1 - \vec{r}_i|^3}(\vec{r}_1 - \vec{r}_i)$$

132. Define electric intensity. Derive an expression for electric intensity at a point situated on the axis of electric dipole.

Ans : **SQP 2020**

The electric field intensity at any point due to source charge is defined as the force experienced per unit positive test charge placed at that point without disturbing the source charge.

It is expressed as,

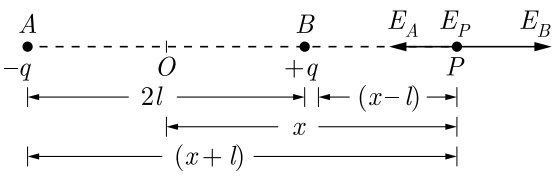
$$E = \frac{F}{q_0}$$

Where, E = electric field intensity and

and F = force experienced by the test charge q_0

It is a vector quantity and its SI unit is NC^{-1}.

We have to calculate the field intensity E at a point P on the axial line of the dipole and at a distance $OP = x$ from the centre O of the dipole.



Electric field on axial line of an electric dipole.

Resultant electric field intensity at the point P,

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$$\vec{E}_P = \vec{E}_A + \vec{E}_B$$

The vectors $\vec{E}_A$ and $\vec{E}_B$ are collinear and opposite.

$$E_P = E_B - E_A$$

Here, $$\vec{E}_A = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{(x+l)^2}$$

and $$\vec{E}_B = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{(x-1)^2}$$

$$E_P = \frac{1}{4\pi\varepsilon_0}\left[\frac{q}{(x-l)^2} - \frac{q}{(x+l)^2}\right]$$

$$= \frac{1}{4\pi\varepsilon_0}\cdot\frac{4qlx}{(x^2-l^2)^2}$$

Hence, $$E_P = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2px}{(x^2-l^2)^2}$$

[Since, $p = q \times 2l$]

In vector from, $$\vec{E}_P = \frac{1}{\pi\varepsilon_0}\cdot\frac{2px}{(x^2-l^2)^2}$$

If dipole is short, i.e., $2l << x$, then

$$E_P = \frac{2|p|}{4\pi\varepsilon_0 x^3} \quad ...(1)$$

The direction of E_P is along BP produced.

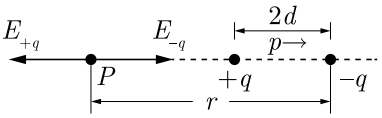
Clearly, $$E_P \propto \frac{1}{x^3}$$

133. An electric dipole of dipole moment p consists of point charges $+q$ and $-q$ separated by a distance 2a apart. Deduce the expression for the electric field E due to the dipole at a distance x from the centre of the dipole on the axial line in terms of the dipole moment p. Hence, show that in the limit

$$x >> a, E = \frac{2p}{(4\pi\varepsilon_0 x^3)}$$

Ans : **Main 2015**

Electric field on an axial line of an electric dipole.



Let P be at distance r from the centre of the dipole on the side of charge $-q$.

Then, the electric field at point P due to charge $-q$ of the dipole is given by

$$E_{-q} = \frac{q}{4\pi\varepsilon_0(r+a)^2}\hat{p}$$

where, $\hat{p}$ is the unit vector along the dipole axis (from $-q$ to q)

Also, the electric field at point P due to charge $+q$ of the dipole is given by

$$E_{+q} = \frac{q}{4\pi\varepsilon_0(r-a)^2}\hat{p}$$

The total field at point P is

$$E = E_{+q} + E_{-q}$$

$$= \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{(r-a)^2} + \frac{1}{(r+a)^2}\right]\hat{p}$$

$$E = \frac{q}{4\pi\varepsilon_0}\cdot\frac{4ar}{(r^2-a^2)^2}\hat{p}$$

Since $r = x$ (given)

$$E = \frac{q}{4\pi\varepsilon_0}\cdot\frac{4ax}{(x^2-a^2)^2}\hat{p}$$

For $x >> a$,

$$E = \frac{4qa}{4\pi\varepsilon_0 x^3}\hat{p}$$

$$E = \frac{2p}{4\pi\varepsilon_0 x^3}$$

134. Define electric flux. State and prove Gauss theorem.

Ans : **Main 2015, 2012**

Electric flux linked with any surface is defined as the total number of electric field lines that normally pass through that surface.

Electric flux $d\phi$ through a small area element dS due to an electric field $\vec{E}$ at an angle θ with dS is,

$$d\phi = E\cdot dS = E\,dS\cos\theta$$

Which is proportional to the number of field lines cutting the area element. Total electric flux ϕ over the whole surface S due to an electric field E,

$$\phi = \oint_S E\cdot dS = \oint_S E\,dS\cos\theta$$

Electric flux is a scalar quantity. But it is a property of vector field.

SI unit of electric flux is N-m^{2}C^{-1}.

Gauss' Theorem :

The surface integral of the electric field intensity over any closed surface (called Gaussian surface) in free space is equal to $\frac{1}{\varepsilon_0}$ times the net charge enclosed within the surface.

$$\phi_E = \oint_S E\cdot dS = \frac{1}{\varepsilon_0}\sum_{i=1}^{n} q_i = \frac{q}{\varepsilon_0}$$

where, $\phi_E = \sum_{i=1}^{n} q_i$ is the algebraic sum of all the charges inside the closed surface.

Hence, total electric flux over a closed surface in vacuum is $\frac{1}{\varepsilon_0}$ times to total charge within the surface, regardless of how the charges may be distributed.

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Proof of Gauss' Theorem :

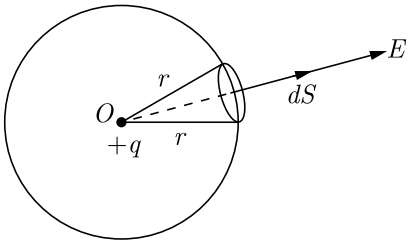
Electric flux through a surface element dS is given by,

$$d\phi_E = E \cdot dS = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r^2}\hat{r} \cdot (dS\,\hat{n})$$

$$d\phi_E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q\,dS}{r^2}\hat{r} \cdot \hat{n}$$

Here, $\hat{r} \cdot \hat{n} = 1.1\cos 0^\circ = 1$

So, $$d\phi_E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q\,dS}{r^2}$$



Total electric flux through the spherical surface,

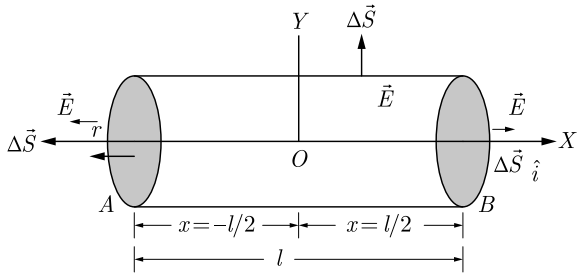
$$\phi_E = \oint_S d\phi_E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r^2}\oint_S dS$$

$$= \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r^2} \cdot 4\pi r^2 = \frac{q}{\varepsilon_0}$$

$$\phi_E = \frac{q}{\varepsilon_0}$$

135. A uniform electric field $\vec{E} = E_x\,\hat{i}$ N/C for $x > 0$ and $\vec{E} = -E_x\,\hat{i}$ N/C for $x < 0$ are given. A right circular cylinder of length l cm and radius r cm has its centre at the origin and its axis along the x-axis. Find out the net outward flux. Using Gauss's law write the expression for the net charge within the cylinder.

Ans : **SQP 2013**



The ends of cylinder are at -1/2 and 1/2 as clearly seen from figure.

We can see from figure, on the left face $\vec{E}$ and $\Delta\vec{S}$ are parallel. Therefore outward flux is

$$\phi_L = \vec{E} \cdot \Delta\vec{S} = -E_x\hat{i} \cdot \Delta\vec{S}$$

$$= +E_x\,\Delta S \quad (\text{since } \hat{i} \cdot \Delta\vec{s} = -\Delta s)$$

On the right face, $\Delta\vec{E}$ and $\Delta\vec{S}$ are parallel, so

$$\phi_R = \vec{E} \cdot \Delta\vec{S}\,E_x\hat{i} \cdot \Delta\vec{S}$$

$$= E_x\,\Delta S$$

For any point on the side of the cylinder, $\vec{E}$ is perpendicular to $\Delta\vec{S}$, hence $\Delta\vec{E} \cdot \Delta\vec{S} = 0$. So, the flux out of the side of the cylinder is zero.

So net outward flux

$$\phi = \phi_L + \phi_R$$

$$= E_x \cdot \Delta S + E_x \cdot \Delta S$$

$$= 2E_x\,\Delta S$$

Here, $\Delta S = \pi r^2$

So, net outward flux $= 2E_x\pi r^2 = 2\pi E_x r^2$

The net charge within the cylinder can be found by using Gauss's law which gives

$$q = \varepsilon_0\phi$$

$$= 2\pi\varepsilon_0 E_x r^2$$

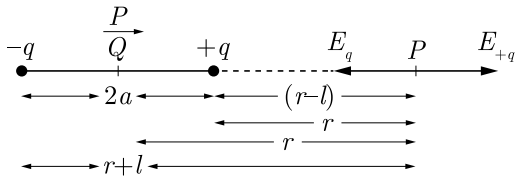
136. (a) Derive an expression for the electric field E due to a dipole of length $2a$ at a point distance r from the centre of the dipole on the axial line.

(b) Draw a graph of E versus r for $r >> a$.

Ans : **SQP 2017, 2014**

(a) Electric field at an axial point of a electric dipole. As shown in figure, consider an electric dipole consisting of charges $+q$ and $-q$ separated by distance $2a$ and placed in vacuum.

Let P be a point on the axial line at distance r from the centre O of the dipole on the side of the charge $+q$.



$$\vec{E}_{-q} = \frac{-q}{4\pi\varepsilon_0(r+a)^2}\hat{p} \qquad \text{(towards left)}$$

where $\hat{p}$ is a unit vector along the dipole axis from $-q$ to $+q$. Electric field due to charge $+q$ at point p is

$$\vec{E}_{+q} = \frac{q}{4\pi\varepsilon_0(r-a)^2}\hat{p} \qquad \text{(towards right)}$$

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Hence, the resultant electric field at point p is

$$\vec{E}_{\text{axial}} = \vec{E}_{+q} + \vec{E}_{-q}$$

$$= \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{(r-a)^2} - \frac{1}{(r+a)^2}\right]\hat{p}$$

$$= \frac{q}{4\pi\varepsilon_0} \cdot \frac{4ar}{(r^2-a^2)^2}\hat{p}$$

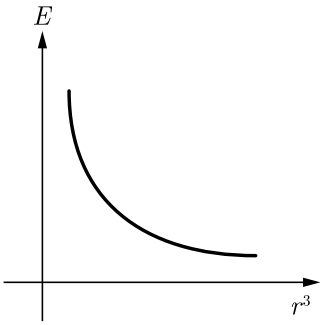
$$\vec{E}_{\text{axial}} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{4qar}{(r^2-a^2)}\hat{p}$$

Here, $p = q \times 2a$ = dipole moment.

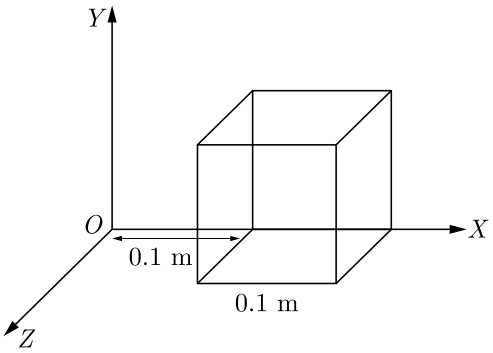
For $r >> a$, a^2 can be neglected compared to r^2

Hence, $\overset{\Leftrightarrow}{E}_{\text{axial}} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2p}{r^3}\hat{p}$

(b)



137. The electric field components due to a charge inside the cube of side 0.1 m are as shown



$E_x = ax$, where $a = 500$ N/C-m

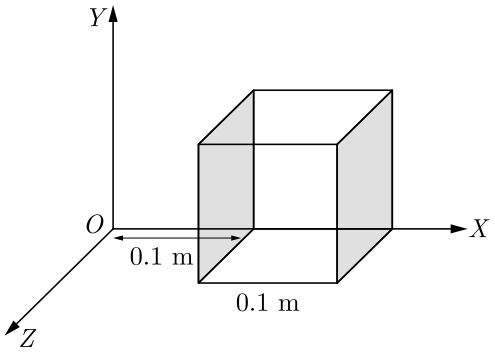
$E_y = 0,\ E_z = 0$

Calculate (i) the flux through the cube and (ii) the charge inside the cube.

Ans : **Main 2018**

(i) Since the electric field has only an x - component for face perpendicular to x direction.

The angle between $\vec{E}$ and $\Delta\vec{S}$ is $\pm\pi/2$



Therefore, the flux $\phi = \vec{E} \cdot \Delta\vec{S}$ is separately zero and for each face of the cube except the two shaded ones. Now the magnitude of the electric field at the left face is

$$E_L = ax = \alpha(0.1) = 0.1\alpha$$

(as $x = 0.1$ at left face)

The magnitude of electric field at the right face is

$$E_R = ax = \alpha(2 \times 0.1) = 0.2\alpha$$

The corresponding flux are

$$\phi_L = \vec{E}_L \cdot \Delta\vec{S}$$

$$= \Delta S\, \vec{E}_1 \cdot \vec{n}_L$$

$$= E_L \Delta S \cos Q \qquad (\text{as } \theta = 180^\circ)$$

$$= -E_L \Delta S = -E_1(a^2)$$

$$= -E_2(0.1)^2$$

Similarly ϕ_R for $\theta = 0^\circ$

$$\phi_R = E_R(a^2) = E_R(0.1)^2$$

So, net flux through the cube

$$= \phi_R + \phi_L$$

$$= E_R(0.1)^2 - E_L(0.1)^2$$

$$= (0.1)^2[0.2a - 0.1\alpha]$$

$$= 0.01 \times 0.1 \times \alpha$$

$$= 0.001 \times 500 = 0.5\ \text{Nm}^2\text{C}^{-1}$$

138. Using Gauss's law obtain the expression for the electric field due to a uniformly charged thin spherical shell of radius R at a point outside the shell. Draw a graph showing the variation of electric field with r, for $r > R$ and $r < R$.

Ans : **Comp 2019, Main 2016**

(i) Electric field intensity at a point outside a uniformly charged thin spherical shell : Consider a uniformly charged thin spherical shell of radius R carrying charge Q. To find the electric field outside the shell, we

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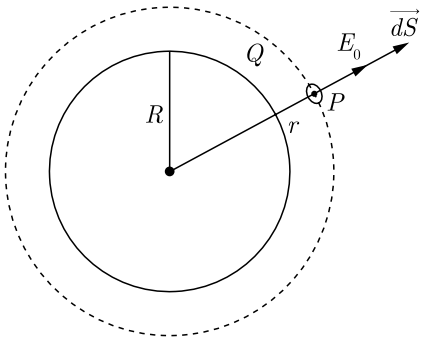
consider a spherical Gaussian surface of radius $(r > R)$, concentric with given shell. If $\vec{E}$ is electric field outside the shell, then by symmetry electric field strength has same magnitude E_0 on the Gaussian surface and is directed radially outward. Also the directions of normal at each point is radially outward, so angle between $\vec{E}_1$ and $\overrightarrow{dS}$ is zero at each point. Hence, electric flux through Gaussian surface $\oint_S = \vec{E}_0 \cdot \overrightarrow{dS}$



$$\oint = E_0\, dS \cos 0 = E_0 \cdot 4\pi r^2$$

Now, Gaussian surface is outside the given charged shell, so charge enclosed by Gaussian surface is Q. Hence, by Gauss's theorem

$$\oint_S = \vec{E}_0 \cdot \overrightarrow{dS}$$

$$= \frac{1}{\varepsilon_0} \times \text{charged enclosed}$$

$$E_0 4\pi r^2 = \frac{1}{\varepsilon_0} \times Q \quad E_0 = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$$

Thus, electric field outside a charged thin spherical shell is the same as if the whole charge Q is concentrated at the centre.

If σ is the surface charge density of the spherical shell, then

$$Q = 4\pi R^2 \sigma \text{ coulomb}$$

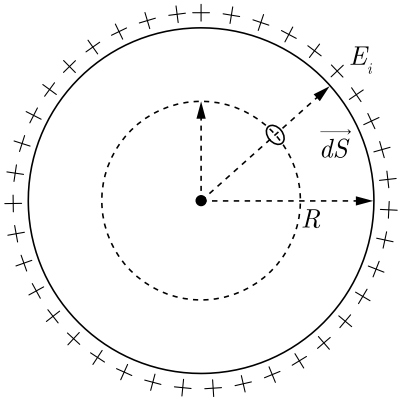
$$E_0 = \frac{1}{4\pi\varepsilon_0}\frac{4\pi R^2\sigma}{r^2} = \frac{R^2\sigma}{\varepsilon_0 r^2}$$

(ii) Electric field inside the shell (hollow charged conducting sphere) The charge resides on the surface of a conductor. Thus a hollow charged conductor is equivalent to a charged spherical shell. To find the electric field inside the shell, we consider a spherical Gaussian surface of radius $(r < R)$, concentric with the given shell. If $\vec{E}$ is the electric field inside the shell, then by symmetry electric field strength has the same magnitude E_i on the Gaussian surface and is directed radially outward.

Also the directions of normal at each point is radially outward, so angle between $\vec{E}_i$ and $\overrightarrow{dS}$ is zero at each point. Hence, electric flux through Gaussian surface

$$= \int_S \vec{E}_i \cdot \overrightarrow{dS} = \int E_i\, dS \cos 0$$

$$= E_i \cdot 4\pi r^2$$



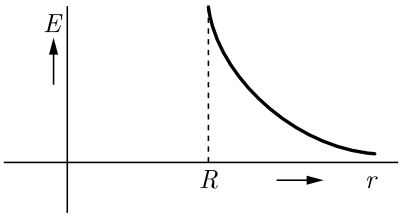
Now, Gaussian surface is inside the given charged shell, so charged shell, so enclosed by Gaussian surface is zero. Hence, by Gauss's theorem

$$\int_S \vec{E}_i \cdot \overrightarrow{dS} = \frac{1}{\varepsilon_0} \times \text{charge enclosed}$$

$$E_i 4\pi r^2 = \frac{1}{\varepsilon_0} \times 0$$

$$E_i = 0$$

Thus, electric field at each point inside a charged thin and spherical shell in zero. The graph is shown in figure.



NUMERICAL QUESTIONS

139. A metal sphere has a charge of $-6\,\mu C$. When 5×10^{12} electrons are removed from the sphere, what would be net charge on it?

Ans : SQP 2015

Here, $q_1 = -6\,\mu C$

and, $q_2 = ne = 5 \times 10^{12} \times 1.6 \times 10^{-19}$

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$$= 8.0 \times 10^{-7}\,\text{C} = 0.8 \times 10^{-6}\,\text{C}$$
$$= 0.8\,\mu\text{C}$$

140. What is the total charge of a system containing five charges $+1, +2, -3, +4$ and -5 in some arbitrary unit?

Ans : **Comp 2018**

As charges are additive in nature, i.e. the total charge of a system is the algebraic sum of all the individual charges located at different points inside the system,

i.e. $q_{\text{net}} = q_1 + q_2 + q_3 + q_4 + q_5$

Hence, Total charge $= +1 + 2 - 3 + 4 - 5$

$= -1$ in the same unit

141. A large hollow metallic sphere has a positive charge of $35.4\,\mu\text{C}$ at its centre. Find how much electric flux emanates from the sphere?

Ans : **Main 2013**

According to the Gauss' law

$$\oint d\phi = \oint \vec{E} \cdot d\vec{S} = q/\varepsilon_0$$

Electric flux $(\phi_E) = \dfrac{q}{\varepsilon_0}$

$$= \frac{35.4 \times 10^{-6}}{8.85 \times 10^{-12}}$$
$$= 4 \times 10^6\,\text{N} - \text{m}^2/\text{C}$$

142. An infinite number of charges each equal to q are placed along X-axis at $x = 1$, $x = 2$, $x = 4$, $x = 8$ and so on. Find the electric field at the point $x = 0$ due to this set up of charges.

Ans : **Main 2025**

At the point $x = 0$, the electric field due to all the charges are in the same negative x- direction and hence get added up, i.e.

$$E = \frac{1}{4\pi\varepsilon_0}\left[\frac{q}{1^2} + \frac{q}{2^2} + \frac{q}{4^2} + \frac{q}{8^2} + \ldots\right]$$
$$= \frac{q}{4\pi\varepsilon_0}\left[1 + \frac{1}{4} + \frac{1}{16} + \frac{1}{64} + \ldots\right]$$
$$= \frac{q}{4\pi\varepsilon_0}\frac{1}{\left[1 - \frac{1}{4}\right]} = \frac{q}{3\pi\varepsilon_0}$$

This electric field is along negative X-axis.

143. How many electrons are there in one coulomb of negative charge?

Ans : **Main 2019, 2015**

The negative charge is due to the presence of excess electrons. Because an electron has a charge whose magnitude is $e = 1.6 \times 10^{-19}\,\text{C}$, the number of electrons is equal to the charge q divided by the charge e on each electron.

Therefore, the number of electrons is

$$n = \frac{q}{e} = \frac{1.0}{1.6 \times 10^{-19}}$$
$$= 6.25 \times 10^{18} \text{ electrons}$$

144. A point charge of $5 \times 10^{-6}\,\text{C}$ experiences a force of $2 \times 10^{-3}\,\text{N}$ when kept in a uniform electric field of intensity E. Then, find the value of E.

Ans : **Main 2012**

Here,

Charge $q = 5 \times 10^{-6}\,\text{C}$

Force $F = 2 \times 10^{-3}\,\text{N}$

Electric field $E = \dfrac{F}{q} = \dfrac{2 \times 10^{-3}\,\text{N}}{5 \times 10^{-6}\,\text{C}}$

$= 400\,\text{N/C}$

145. Find the electric dipole moment electron and a proton which distance is 4.3 nm apart.

Ans : **SQP 2015**

Charge, $q = 1.6 \times 10^{-19}$

$d = 4.3 \times 10^{-9}\,\text{cm}$

Dipole moment, $p = q \times d$

$= 1.6 \times 10^{-19} \times 4.3 \times 10^{-9}$

$= 6.8 \times 10^{-28}\,\text{C} - \text{m}$

146. What is the electric dipole moment of an electric dipole made up of two opposite charges having magnitude $+3.2 \times 10^{-19}\text{C}$ and $-3.2 \times 10^{-19}\text{C}$ separates by a distance 2.4×10^{-10} m ?

Ans : **Main 2013**

Here,

Magnitude of charge, $q = 3.2 \times 10^{-19}\,\text{C}$

Length of dipole, $2l = 2.4 \times 10^{-10}\,\text{m}$

Electric dipole moment,

$$p = q \times 2l$$
$$= 3.2 \times 10^{-19} \times 2.4 \times 10^{-10}$$
$$= 7.68 \times 10^{-29}\text{C-m}$$

147. An infinite line charge produces a field of $9 \times 10^4\,\text{N/C}$ at a distance of 2 cm. Calculate the linear charge density.

Ans : **SQP 2008**

Here, $E = 9 \times 10^4\,\text{N/C}$

$r = 2\,\text{cm} = 2 \times 10^{-2}\,\text{m}$

and $\lambda = ?$

$$E = \frac{\lambda}{2\pi\varepsilon_0 r}$$
$$\lambda = 2\pi\varepsilon_0 r E$$

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$$= \frac{1}{2 \times 9 \times 10^9} \times 2 \times 10^{-2} \times 9 \times 10^4$$
$$= 10^{-7}\,\text{Cm}^{-1}$$

148. A charged oil drop weighing $1.6 \times 10^{-15}\,\text{N}$ is found to remain suspended in a uniform electric field of intensity $2 \times 10^3\,\text{NC}^{-1}$. Find the charge on the drop.

Ans : **Main 2016**

Here, the weight of a charged oil drop is equal to the force on the drop due to uniform electric field.

Force, $F = 1.6 \times 10^{-15}\,\text{N}$

Electric field intensity,

$$E = 2 \times 10^3\,\text{NC}^{-1}$$

Force, $F = qE$

$$q = F/E$$
$$= 1.6 \times 10^{-15}/2 \times 10^3$$
$$q = 8 \times 10^{-19}\,\text{C}$$

149. Maximum torque acting on an electric dipole of dipole moment 3×10^{-29} C-m in a uniform electric field E is $6 \times 10^{-25}\,\text{N} - \text{m}$. Find the value of E.

Ans : **Main 2017**

Torque, $\tau = 3 \times 10^{-29}\,\text{Cm}$

$$p = 6 \times 10^{-25}\,\text{Nm}$$
$$\tau = \vec{p} \times \vec{E} = pE\sin\theta$$

For maximum value,

$$\theta = 90^\circ$$
$$\tau = pE$$
$$3 \times 10^{-29} = 6 \times 10^{-25} \times E$$
$$E = \frac{3 \times 10^{-29}}{6 \times 10^{-25}} = 0.5 \times 10^{-29+25}$$
$$= 0.5 \times 10^{-4}\,\text{N/C}$$

150. The dielectric constant of water is 80. What is its permittivity?

Ans : **SQP 2013**

Here, $K = 80$

We have, $K = \frac{\varepsilon_m}{\varepsilon_0}$

Hence, $\varepsilon_m = K\varepsilon_0$

[Since, $\varepsilon_0 = 8.85 \times 10^{-12}\,\text{C}^2\text{N}^{-1}\text{m}^{-2}$]

$$= 80 \times 8.85 \times 10^{-12}$$
$$= 708 \times 10^{-12}$$
$$= 7.08 \times 10^{-10}\,\text{C}^2\text{N}^{-1}\text{m}^{-2}$$

151. Calculate the amount of work done in turning an electric dipole of dipole moment 3×10^{-8} cm from its position of unstable equilibrium to the position of stable equilibrium in a uniform electric field of intensity 10^3 N/C.

Ans : **SQP 2010**

For unstable equilibrium, the angle between $\vec{p}$ and $\vec{E}$ is $\theta_1 = 180^\circ$

Finally, for stable equilibrium, $\theta_2 = 0^\circ$

Required work done

$$W = pE(\cos\theta_1 - \cos\theta_2)$$
$$= 3 \times 10^{-8} \times 10^3(\cos 180^\circ - \cos 0^\circ)$$

Since $[\cos 180^\circ = -1, \cos 0^\circ = +1]$

$$W = -6 \times 10^{-5}\,\text{J}$$

152. Intensity of electric field at a perpendicular distance of 0.5 m from an infinitely long line charge having linear charge density (λ) is $3.6 \times 10^3\,\text{Vm}^{-1}$. Find the value of λ.

Ans : **Main 2024**

By applying Gauss' theorem, electric field due to an infinitely long straight charged wire is,

$$E = \frac{1}{2\pi\varepsilon_0} \cdot \frac{\lambda}{r}$$

where, $\frac{1}{2\pi\varepsilon_0} = 2 \times 9 \times 10^9\,\text{mF}^{-1}$

λ = linear charge density

$r = 0.5$ m

$$E = 3.6 \times 10^3\,\text{Vm}^{-1}$$
$$3.6 \times 10^3 = \frac{2 \times 9 \times 10^9 \times \lambda}{0.5}$$
$$\lambda = \frac{3.6 \times 10^3 \times 0.5}{2 \times 9 \times 10^9} = 10^{-7}\,\text{Cm}^{-1}$$

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153. Two point charges having equal charges separated by 1 m distance experience a force of 8 N. What will be the force experienced by them, if they are held in water, at the same distance? (Given : $K_{\text{water}} = 80$)

Ans : **SQP 2018, 2014**

Two point charges system is taken from air to water keeping other variables (e.g. distance, magnitude of charge) unchanged. So, the only factor which may affect the interacting force is dielectric constant of medium.

Force acting between two point charges.

$$F = \frac{1}{4\pi\varepsilon_0 K}\frac{|q_1 q_2|}{r^2}$$

$$F \propto \frac{1}{K}$$

$$\frac{F_{\text{air}}}{F_{\text{Medium}}} = K$$

$$\frac{8}{F_{\text{water}}} = 80$$

$$F_{\text{water}} = \frac{8}{80} = \frac{1}{10}\,\text{N}$$

154. A charge $q = 1\,\mu\text{C}$ is placed at point $(1\,\text{m}, 2\,\text{m}, 4\,\text{m})$. Find the electric field at point $P(0\,\text{m}, -4\,\text{m}, 3\,\text{m})$.

Ans : **Main 2011**

Here, $r_q = \hat{i} + 2\hat{j} + 4\hat{k}$

and $r_p = -4\hat{j} + 3\hat{k}$

Hence, $r_p - r_q = -\hat{i} - 6\hat{j} - \hat{k}$

$$|r_p - r_q| = \sqrt{(-1)^2 + (-6)^2 + (-1)^2} = \sqrt{38}\ \text{m}$$

Now, Electric field, $E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{|r_p - r_q|^3}(r_p - r_q)$

Substituting the values, we get

$$E = \frac{(9.0 \times 10^9)(1.0 \times 10^{-6})}{(38)^{3/2}}(-\hat{i} - 6\hat{j} - \hat{k})$$

$$= (-38.42\hat{i} - 230.52\hat{j} - 38.42\hat{k})\,\text{N/C}$$

155. The opposite corners of a square carry Q charge each and the other two opposite corners of the same square carry q charge each. If the resultant force on q is zero, how are Q and q related?

Ans : **SQP 2010**

Let each side of square be x.

Diagonal $= \sqrt{x^2 + x^2} = x\sqrt{2}$

$$F_1 = F_2 = \frac{Qq}{4\pi\varepsilon_0 x^2}$$

and $$F_3 = \frac{qq}{4\pi\varepsilon_0 (x\sqrt{2})^2} = \frac{q^2}{2 \times 4\pi\varepsilon_0 x^2}$$

As, F_1 and F_2 are perpendicular to each other, their resultant force.

$$F = \sqrt{F_1^2 + F_2^2} = \sqrt{F_1^2 + F_1^2}$$

$$F = F_1\sqrt{2}$$

As, net force on q is zero. Therefore,

$$F_1\sqrt{2} = -F_3$$

$$\frac{Qq\sqrt{2}}{4\pi\varepsilon_0 x^2} = \frac{-q^2}{2 \times 4\pi\varepsilon_0 x^2}$$

$$q = -2\sqrt{2}\,Q$$

156. Two charges of $+25 \times 10^{-9}\,\text{C}$ and $-25 \times 10^{-9}\,\text{C}$ are placed 6 m apart. Find the electric field at a point 4 m from the centre of the electric dipole

Ans : **Main 2019**

1. On axial line
2. On equatorial line.

Here, $q = 25 \times 10^{-9}\,\text{C}$

$2r = 6\,\text{m},\ r = 4\,\text{m}$

$p = q(2r) = 25 \times 10^{-9} \times 6$

$= 1.5 \times 10^{-7}\,\text{C} - \text{m}$

Now, $E_{\text{axial}} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2pr}{(r^2 - a^2)^2}$

$$= \frac{9 \times 10^9 \times 2 \times 1.5 \times 10^{-7} \times 4}{(4^2 - 3^2)^2}$$

$$= \frac{2700 \times 4}{49} = 220.4\,\text{NC}^{-1}$$

Hence, $E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{p}{(r^2 + a^2)^{3/2}}$

$$= \frac{9 \times 10^9 \times 1.5 \times 10^{-7}}{(4^2 + 3^2)^{3/2}}$$

$$= \frac{1350}{125} = 10.8\,\text{N} - \text{C}^{-1}$$

157. A particle of mass 10^{-3} kg and charge $5\,\mu\text{C}$ enters into a uniform electric field of 2×10^5 NC^{-1}, moving with a velocity of $20\,\text{ms}^{-1}$ in a direction opposite to that of the field. Calculate the distance it would travel before coming to rest.

Ans : **Main 2012**

Here, $m = 10^{-3}$ kg, $q = 5 \times 10^{-6}\,\text{C}$,

$E = 2 \times 10^5$ N/C,

$u = 20$ m/s, $v = 0$

As it enters opposite to the field, so particle will retard.

Acceleration,

$$a = \frac{qE}{m}$$

$$= \frac{5 \times 10^{-6} \times 2 \times 10^5}{10^{-3}}$$

$$= 10^2\,\text{m/s}^2$$

Using $v^2 = u^2 - 2as$, we get

$0 = (20)^2 - 2 \times 1000 \times s$

or $s = \frac{400}{2000}$

$= \frac{1}{5} = 0.2$ m

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158. Two charges q_1 and q_2 of $0.1\,\mu C$ and $-0.1\,\mu C$ respectively are 10 Å apart. What is the electric field at a point on the line joining them at a distance of 10 cm from their mid-point?

Ans : Comp 2006, 2004

Here, $q_1 = q_2 = q = 0.1\,\mu C$

$= 10^{-13}\,C$ [in magnitude]

Length of the electric dipole formed by these charges,

$2a = 10^{-10}\,m = 10^{-9}\,m$

Thus, electric dipole moment,

$p = 2aq = 10^{-13} \times 10^{-9}$

$= 10^{-22}\,C - m$

Distance of the point under consideration on the axial line from the mid-point,

$r = 10\,cm = 0.1\,m$

Since, $a << r$, electric field at a point on the axial line,

$$E = k_c \frac{2p}{r^3}$$

$$= (9 \times 10^9)\frac{2 \times 10^{-22}}{(0.1)^3}$$

$$= 18 \times 10^{-10}\,N/C$$

159. When a test charge of 2 nC is placed at the origin, it experiences a force of $8 \times 10^{-4}\,N$ in the positive y-direction. What is the electric field at the origin? What would be the force on a charge – 4 nC placed at the origin?

Ans : Main 2011

Here,

Charge, $q_0 = 2\,nC = 2 \times 10^{-9}\,C$

Force, $F = 8 \times 10^{-4}\,N$

$q_1 = -4\,nC$

$= -4 \times 10^{-9}\,C$

Electric field at origin,

$$E = \frac{F}{q_0} = \frac{8 \times 10^{-4}}{2 \times 10^{-9}}$$

$$= 4 \times 10^5\,N/C$$

Along positive y-direction.

Force at origin $F = q_1 E$

$= -4 \times 10^{-9} \times 4 \times 10^5$

$= -16 \times 10^{-4}\,N$

Along negative y-direction.

160. Two point charges of magnitude $2 \times 10^{-7}\,C$ and $8.5 \times 10^{-8}\,C$ are 0.1 m apart. Calculate the electric field intensity that each charge produces at the site of the other.

Ans : SQP 2008, 2005

Here, $q_1 = 2 \times 10^{-7}\,C$,

$q_2 = 8.5 \times 10^{-8}\,C$,

$r = 0.1\,m$

Electric field at the side of q_2,

$$E_1 = \frac{q_1}{4\pi\varepsilon_0 r^2}$$

$$= \frac{2 \times 10^{-7} \times 9 \times 10^9}{(0.1)^2}$$

$$= 1.8 \times 10^5\,N/C$$

Electric field at the side of q_1,

$$E_2 = \frac{q_2}{4\pi\varepsilon_0 r^2}$$

$$= \frac{8.5 \times 10^{-8} \times 9 \times 10^9}{(0.1)^2}$$

$$= 7.6 \times 10^4\,N/C$$

161. A sphere of lead of mass 10 g has net charge $-2.5 \times 10^{-9}\,C$.

1. Find the number of excess electrons on the sphere.
2. How many excess electrons are per lead atom? Atomic number of lead is 82 and its atomic mass is 207 g/mol.

Ans : Main 2020

1. The charge of an electron $= -1.6 \times 10^{-19}\,C$

   Net charge on sphere $= -2.5 \times 10^{-9}\,C$

   So, the number of excess electrons

   $$= \frac{-2.5 \times 10^{-9}\,C}{-1.6 \times 10^{-19}\,C}$$

   $$= 1.5 \times 10^{10}\text{ electrons}$$

2. Atomic number of lead is 82.
   Atomic mass of lead is 207 g/mol.
   Hence, 10 g of lead will have

   $$\frac{10\,g}{207\,g/mol} \times 6.02 \times 10^{23}\,atoms/mol$$

   $$= 2.91 \times 10^{22}\,atoms$$

   Hence, the number of excess electrons per atom

   $$= \frac{1.56 \times 10^{10}}{2.91 \times 10^{22}}$$

   $$= 5.36 \times 10^{-13}\text{ electrons}$$

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162. An electric dipole of length 4 cm when placed with its axis making an angle of 60° with a uniform electric field, experiences a torque of $4\sqrt{3}$ Nm. Calculate the potential energy of the dipole if it has charge ± 8 nC.

Ans : **Main 2014**

Here, length $2a = 4 \text{ cm} = 4 \times 10^{-2} \text{ m}$

Angle, $\theta = 60^\circ$

Torque, $t = 4\sqrt{3} \text{ Nm}$

Charge, $Q = 8 \times 10^{-9} \text{ C}$

$t = Q(2a)E\sin\theta$

Electric field,

$$E = \frac{t}{Q(2a)\sin\theta}$$

$$= \frac{4\sqrt{3}}{8 \times 10^{-9} \times 4 \times 10^{-2} \times \sin 60^0} \text{N/C}$$

Potential energy,

$$C = -pE\cos\theta = Q(2a)E\cos\theta$$

$$U = -8 \times 10^{-9} \times 4 \times 10^{-2} \times \frac{4\sqrt{3} \times \cos 60^\circ}{8 \times 10^{-9} \times 4 \times 10^{-2} \times \sin 60^\circ}$$

$$= \frac{-4\sqrt{3}}{\sqrt{3}} \text{J} = -4\text{J}$$

163. An electric dipole as held in a uniform electric field.

(i) Show that the net force acting on it is zero.

(ii) The dipole is aligned parallel to the field. Find the work done in rotating it through the angle of 180°.

Ans : **SQP 2018**

(i) The dipole moment of dipole is

$$\left|\vec{p}\right| = q \times (2a)$$

Force on $-q$ at $A = -q\vec{E}$

Force on $+q$ at $B = +q\vec{E}$

Net force on the dipole $= q\vec{E} - q\vec{E} = 0$

(ii) Work done on dipole

$$W = \Delta U$$

$$= pE(\cos\theta_2 - \cos\theta_2)$$

$$= pE(\cos 0^\circ - \cos 180^\circ)$$

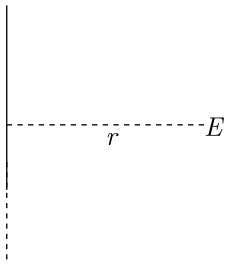
$$W = 2pE$$

164. An infinite line charge produces a field of $9 \times 10^4 \text{ NC}^{-1}$ at a distance of 2 cm. Calculate the linear charge density.

Ans : **Main 2006**

We know, $\vec{E}$ can be calculated by applying Gauss' law. Now, by putting the value of $\vec{E}$ in the equation. We can calculate the charge density in the wire. We know that electric field intensity at distance (r) due to infinite line charge is

$$E = \frac{1}{4\pi\varepsilon_0} \cdot \left(\frac{2\lambda}{r}\right)$$



$$E = \frac{1}{2\pi\varepsilon_0}\left(\frac{\lambda}{r}\right) \Rightarrow \lambda = E \times 2\pi\varepsilon_0 r$$

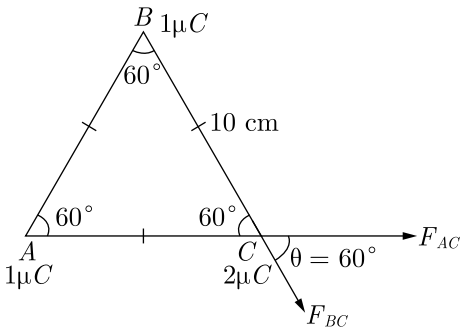
$$\lambda = 9 \times 10^4 \times 2 \times 3.14 \times 8.85 \times 10^{-12} \times 0.02$$

$$\lambda = 10^{-7} \text{ C/m}$$

165. Three charges 1 μC, 1 μC and 2 μC are kept at vertices A, B and C of an equilateral triangle ABC of 10 cm side respectively. What will the resultant force on the charge at C ?

Ans : **Main 2015**

The situation is shown as below



Force on C due to A

$$F_{AC} = \frac{1}{4\pi\varepsilon_0}\frac{q_A q_C}{(AC)^2}$$

$$= \frac{9 \times 10^9 \times 1 \times 10^{-6} \times 2 \times 10^{-6}}{(10 \times 10^{-2})^2}$$

$$= 1.8 \text{ N}$$

Similarly,

$$F_{BC} = \frac{1}{4\pi\varepsilon_0}\frac{q_B q_C}{(BC)^2}$$

NODIA

$$= \frac{9 \times 10^9 \times 1 \times 10^{-6} \times 2 \times 10^{-6}}{(10 \times 10^{-2})^2}$$

$$= 1.8\,\text{N}$$

Resultant force on the charge at C,

$$F_{\text{resultant}} = \sqrt{F_{AC}^2 + F_{BC}^2 + 2F_{AC}F_{BC}\cos 60^\circ}$$

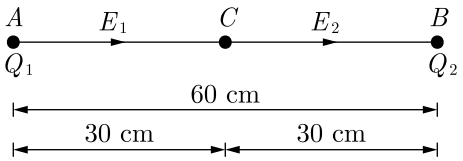
$$= \sqrt{(1.8)^2 + (1.8)^2 + 2(1.8)^2 \times \frac{1}{2}}$$

$$= 3.12\,\text{N}$$

166. Two point charges $Q_1 = 400\,\mu\text{C}$ and $Q_2 = 100\,\mu\text{C}$ are kept fixed, 60 cm apart in vacuum. Find intensity of the electric field at mid-point of the line joining $Q_1$and Q_2.

Ans : **Main 2016, 2010**

As per given data in the question we can draw the following diagram:



Since, two point charges $Q_1 = 400\,\mu\text{C}$ and $Q_2 = 100\,\mu\text{C}$are kept fixed, 60 cm apart in vacuum. In the figure, C is the mid-point of AB, where we need to determine the electric field intensity.

So, net electric field,

$$E = E_1 - E_2 = \frac{kQ_1}{r^2} - \frac{kQ_2}{r^2}$$

$$= \frac{k}{r^2}(Q_1 - Q_2)$$

$$= \frac{9 \times 10^9}{(30 \times 10^{-2})^2}(400 \times 10^{-6} - 100 \times 10^{-6})$$

$$= \frac{9 \times 10^9 \times 300 \times 10^{-6}}{900 \times 10^{-4}}$$

$$= 3 \times 10^7\,\text{N/C}$$

167. An electric dipole consists of two opposite charges each of $10^{-4}\,\text{C}$ separated by 0.5 cm. If dipole is placed in an external uniform field of $10^6\,\text{N-C}^{-1}$, how much work is done in rotating the dipole through 180°, (starting from the position $\theta = 0^\circ$)?

Ans : **SQP 2019**

Given, Magnitude of each charge on dipole,

$$q = 10^{-4}\,\text{C}$$

Distance between the charge,

$$2a = 0.5\,\text{cm} = 0.5 \times 10^{-2}\,\text{m}$$

Electric field, $E = 10^6\,\text{N-C}^{-1}$

Initial angle of dipole with electric field, $\theta_1 = 0^\circ$.

and final angle of dipole with electric field, $\theta_2 = 180^\circ$.

Electric dipole moment,

$$p = q \times 2a$$

$$= 10^{-4} \times (0.5 \times 10^{-2})$$

$$= 0.5 \times 10^{-6}\,\text{C-m}$$

Therefore, work done in rotating the electric dipole in uniform electric field,

$$W = pE(\cos\theta_1 - \cos\theta_2)$$

$$= (0.5 \times 10^{-6}) \times 10^6 \times (\cos 0^\circ - \cos 180^\circ)$$

$$= 0.5 \times [1 - (-1)] = 1$$

168. Two charges of $\pm 1000\,\mu\text{C}$ are separated by 2 mm. The dipole so formed is held at an angle of 30° with a uniform electric field of $8 \times 10^5\,\text{N-C}^{-1}$. Find out the value of torque acting on the dipole?

Ans : **Main 2024**

Given, Magnitude of each charge on dipole,

$$q = 1000\,\mu\text{C} = 10^{-3}\text{C}$$

Distance between the charges,

$$2a = 2\,\text{mm} = 2 \times 10^{-3}\text{m}$$

Angle of dipole with direction of electric field, $\theta = 30^\circ$.

and Electric field, $E = 8 \times 10^5\,\text{N-C}^{-1}$

Dipole moment, $p = q \times 2a$

$$= 10^{-3} \times (2 \times 10^{-3})$$

$$= 2 \times 10^{-6}\,\text{C-m}$$

Therefore, torque acting on the dipole in uniform electric field,

$$\tau = pE\sin\theta$$

$$= (2 \times 10^{-6}) \times (8 \times 10^5) \times \sin 30^\circ$$

$$= 0.8\,\text{N-m}$$

169. A regular hexagon of side 10 cm has charge $5\,\mu\text{C}$ at each of its vertices. What is the resultant potential at the centre of the hexagon?

Ans : **SQP 2017, 2012**

Here,

Side of hexagon, $a = 10\,\text{cm} = 0.1\,\text{m}$

and Charge at each vertex,

$$q = 5\,\mu\text{C} = 5 \times 10^{-6}\text{C}$$

The distance of each charge from the centre of regular hexagon,

$$r = a = 0.1\,\text{m}$$

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We also know that, resultant potential at the centre of hexagon,

$$V = k\left[\frac{q_1+q_2+q_{3+}q_4+q_5+q_6}{r}\right]$$
$$= k\left[\frac{q+q+q+q+q+q}{r}\right]$$
$$= k \cdot \frac{6q}{r}$$
$$= (9\times10^9)\times\frac{6\times(5\times10^{-6})}{0.1}$$
$$= 27\times10^5\ \text{V}$$

where, k = Electrostatic force constant
$= 9\times10^9\ \text{N-m}^2\text{-C}^{-2}$

170. A square of side 1 m, has four charges of $+2\times10^{-9}$ C, $+1\times10^{-9}$ C, -2×10^{-9} C and -3×10^{-9} C respectively at its corners. What is the resultant potential at the centre of the square?

Ans : **Main 2012**

Here,

Side of square, $a = 1$ m

First charge, $q_1 = 2\times10^{-9}$ C

Second charge, $q_2 = 1\times10^{-9}$ C

Third charge, $q_3 = -2\times10^{-9}$ C

Fourth charge, $q_4 = -3\times10^{-9}$ C

The distance of each charge form the centre of the square,

$$r = \frac{\sqrt{a^2+a^2}}{2}$$
$$= \frac{\sqrt{(1)^2+(1)^2}}{2}$$
$$= 0.707\ \text{m}$$

Therefore, potential at the centre of square,

$$V = k\left[\frac{q_1+q_2+q_3+q_4}{r}\right]$$
$$= k\left[\frac{[(2\times10^{-9})+(1+10^{-9})+(-2\times10^{-9})+(-3\times10^{-9})]}{0.707}\right]$$
$$= k\times(-2.83\times10^{-9})$$
$$= (9\times10^9)\times(-2.83\times10^{-9})$$
$$= 25.5\ \text{V}$$

Where, k = Electrostatic force constant
$= 9\times10^9\ \text{N-m}^2\text{-C}^{-2}$

171. Two spherical conductors of radii 4 cm and 5 cm are charged to the same potential. If σ_1 and σ_2 be the respective values of the surface density of charge on both the conductors, What is the ratio of $\frac{\sigma_1}{\sigma_2}$?

Ans : **Main 2025**

Radius of first conductor, $r_1 = 4$ cm

Radius of second conductor, $r_2 = 5$ cm

Potential on first conductor, $V_1 = V_2$

where, V_2 = potential on second conductor

Surface density of charge on first conductor $= \sigma_1$, and surface density of charge on second conductor $= \sigma_2$.

Electric potential, $V = k\cdot\frac{q}{r}$

$q \propto r$ (as potential is same)

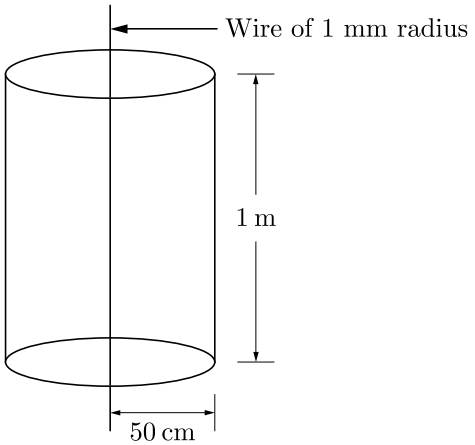
Therefore, $\frac{q_1}{q_2} = \frac{r_1}{r_2}$

We also know that, surface charge density of a sphere,

$$\sigma = \frac{\text{Charge on sphere}}{\text{Surface area of sphere}}$$
$$= \frac{q}{4\pi r^2} \propto \frac{q}{r^2}$$

Therefore, $\frac{\sigma_1}{\sigma_2} = \frac{q_1}{q_2}\times\left[\frac{r_2}{r_1}\right]^2$
$= \frac{r_1}{r_2}\times\left[\frac{r_2}{r_1}\right]^2 = \frac{r_2}{r_1} = \frac{5}{4}$

172. Electric charge is uniformly distributed along a long straight wire of radius 1 mm. The charge per cm length of the wire is Q coulomb. A cylindrical surface of radius 50 cm and length 1 m symmetrically encloses the wire as shown in the figure. Find out the total electric flux passing through the cylindrical surface?



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Ans : **Comp 2009, 2007**

Given,

Radius of wire, $r = 1\,\text{mm}$

Charge on the wire per cm length $= Q$.

Charge on 1 meter long wire

$$= Q \times 100$$

$$= 100\,Q \text{ coulomb}$$

Length of cylinder, $l = 1\,\text{m} = 100\,\text{cm}$

and radius of cylinder,

$$R = 50\,\text{cm}$$

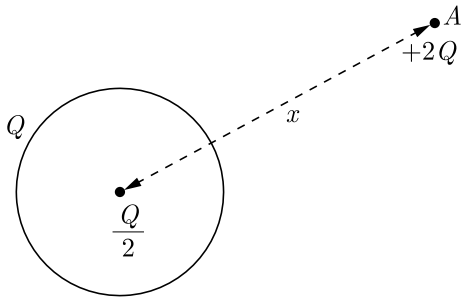
We know from the Gauss's theorem that total electric flux passing through the cylindrical surface,

$$\phi = \frac{\text{Charge enclosed by the cylinder}}{\varepsilon_0}$$

$$= \frac{\text{Charge on one metre length of wire}}{\varepsilon_0}$$

$$= \frac{100\,Q}{\varepsilon_0}$$

173. A thin metallic spherical shell of radium R carries a charge Q on its surface. A point charge $\frac{Q}{2}$ is placed at the centres C and other charge $+2Q$ is placed outside the shell at A at a distance X from the centre as shown in the figure.



(i) Find the electric flux through the shell.

(ii) State the law used.

(iii) Find the force on the charges at the centre C of the shell and at the point A.

Ans : **Main 2016**

(i) Electric flux through a Gaussian surface,

$$\phi = \frac{\text{Total enclosed charge}}{\varepsilon_0}$$

Total enclosed charge $= Q + \frac{Q}{2} = \frac{3Q}{2}$

Hence electric flux through the shell

$$\phi = \frac{3Q}{2\varepsilon_0}$$

(ii) **Gauss's Law :** Electric flux through a Gaussian surface is $\frac{1}{\varepsilon_0}$ times the net charge enclosed within it.

Mathematically,

$$\oint \vec{E} \cdot \overrightarrow{dS} = \frac{1}{\varepsilon_0} \times q$$

(iii) We know that electric field or net charge inside the spherical conducting shell is zero. Hence, the force on charge $\frac{Q}{2}$ is zero.

Force on charge at A,

$$F_A = \frac{1}{4\pi\varepsilon_0} \frac{2Q \times \left(Q + \frac{Q}{2}\right)}{x^2}$$

$$= \frac{1}{4\pi\varepsilon_0} \frac{3Q^2}{x^2}$$

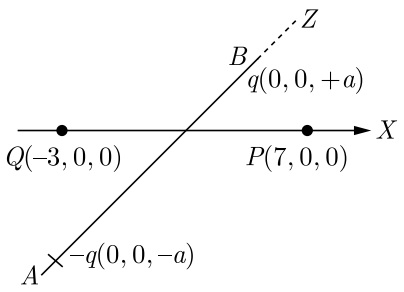
174. (i) Can two equipotential surfaces intersect each other? Give reasons.

(ii) Two charges $-q$ and $+q$ are located at points $A(0,0,-a)$ and $B(0,0,+a)$ respectively. How much work is done in moving a test charge from point $P(7,0,0)$ to $Q(-3,0,0)$?

Ans : **Comp 2024**

(i) No, if two equipotential surfaces (as these are normal to electric field) intersect each other, then at the point of intersection there will be two directions of electric field, which is impossible. Hence, two equipotential surfaces cannot intersect each other.

(ii) Suppose W_1 and W_2 be the work done in moving a test charge q_0 from $P(7,0,0)$ to $Q(-3,0,0)$ in the fields of $+q(0,0,a)$ and $-q(0,0,-a)$ respectively.



Here, $\overrightarrow{BP} = 7\hat{i} + a\hat{k}$,

$\overrightarrow{BQ} = -3\hat{i} - a\hat{k}$

$\overrightarrow{AP} = 7\hat{i} - a\hat{k}$,

$\overrightarrow{AQ} = -3\hat{i} - a\hat{k}$s

$BP = \sqrt{49 + a^2}$,

$BQ = \sqrt{9 + a^2}$

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$$AP = \sqrt{49 + a^2},$$
$$AQ = \sqrt{9 + a^2}$$

From the relation,

$$W_{AB} = \frac{1}{4\pi\varepsilon_0} \cdot q\left(\frac{1}{r_B} - \frac{1}{r_A}\right)$$
$$W_1 = \frac{1}{4\pi\varepsilon_0} \cdot q\left(\frac{1}{BQ} - \frac{1}{BP}\right)$$
$$= \frac{1}{4\pi\varepsilon_0} \cdot q\left(\frac{1}{\sqrt{9 + a^2}} - \frac{1}{\sqrt{49 + a^2}}\right)$$

and $$W_2 = \frac{1}{4\pi\varepsilon_0} \cdot (-q)\left(\frac{1}{AQ} - \frac{1}{AP}\right)$$

or $$W_2 = \frac{-q}{4\pi\varepsilon_0}\left(\frac{1}{\sqrt{9 + a^2}} - \frac{1}{\sqrt{49 + a^2}}\right)$$

Hence, Total work done,

$$W = W_1 + W_2$$
$$= \frac{q}{4\pi\varepsilon_0}\left(\frac{1}{\sqrt{9 + a^2}} - \frac{1}{\sqrt{49 + a^2}} - \frac{1}{\sqrt{9 + a^2}} + \frac{1}{\sqrt{49 + a^2}}\right)$$
$$= 0 \text{ (zero)}$$

175. Two pith balls of mass 0.2 gm each are suspended by two nylon strings of length 50 cm each. They are charged with charge of equal magnitude and same nature. If they come to rest after repulsion at a distance of 4 cm, then find the charge on each ball.

Comp 2020, 2018

Ans :

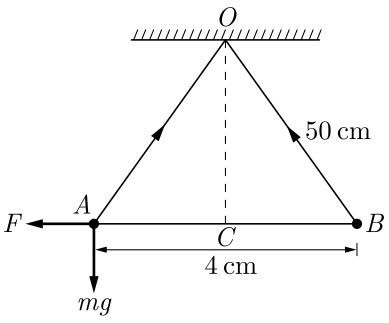
Here,

Distance between ball,

$$r = 4\,\text{cm} = 4 \times 10^{-2}\ \text{m}$$

Let the charge on each ball is Q. Then force of repulsion between two ball is given by,

$$F = \frac{1}{4\pi\varepsilon_0}\frac{Q \cdot Q}{(4 \times 10^{-2})^2}$$



$$F = \frac{Q^2 \times 9 \times 10^9}{16 \times 10^{-4}} \quad ...(1)$$

Weight of each ball = mg

Here, $$m = 0.2 \times 10^{-3}\,\text{kg}$$
$$= 0.2 \times 10^{-3} \times 9.8$$
$$= 1.96 \times 10^{-3}\,\text{N} \quad ...(2)$$

If tension in string is T and ball are in equilibrium then algebraic sum of moments of force acting on it is zero.

$$F \times OC - Mg \times AC + T \times 0 = 0$$

or $$F \times OC = mg \times AC$$
$$\frac{F}{mg} = \frac{AC}{OC}$$

Since in $\Delta\, OAC$,

$$OA^2 = AC^2 + OC^2$$
$$OC = \sqrt{OA^2 - AC^2}$$

Now, $$\frac{F}{mg} = \frac{AC}{\sqrt{OA^2 - AC^2}}$$
$$= \frac{AB/2}{\sqrt{(OA)^2 - \left(\frac{AB}{2}\right)^2}}$$
$$= \frac{4 \times 10^{-2}/2}{(50 \times 10^{-2})^2 - (2 \times 10^{-2})^2}$$
$$= \frac{2 \times 10^{-2}}{\sqrt{(50 \times 10^{-2})^2 - (2 \times 10^{-2})^2}}$$
$$= \frac{2 \times 10^{-2}}{10^{-2}\sqrt{2500 - 4}}$$
$$= \frac{2 \times 10^{-2}}{49.95 \times 10^{-2}} = \frac{2}{49.95}$$

From the equation 1 and 2, we get

$$\frac{Q^2 \times 9 \times 10^9}{16 \times 10^{-4} \times 1.96 \times 10^{-3}} = \frac{2}{49.95}$$
$$s = \frac{2 \times 16 \times 10^{-4} \times 1.96 \times 10^{-3}}{9 \times 10^{-9} \times 49.95}$$
$$Q = \sqrt{1.39 \times 10^{-17}}$$
$$= 3.73 \times 10^{-9}$$
$$= 3.73\,\mu\text{C}$$

CASE BASED QUESTIONS

176. For electrostatics, the concept of electric field is convenient, but not really necessary. Electric field is an elegant way of characterizing the electrical environment of a system of charges. Electric field at a point in the space around a system of charges tells you the force a unit positive test charge would experience if placed at that point (without disturbing the system). Electric field

is a characteristic of the system of charges and is independent of the test charge that you place at a point to determine the field. The term field in physics generally refers to a quantity that is defined at every point in space and may vary from point to point. Electric field is a vector field, since force is a vector quantity.

(a) What do you mean by electric field ?

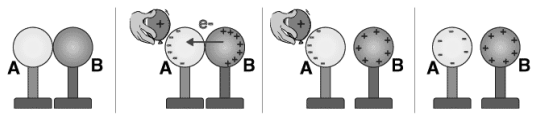
(b) What is the SI unit of electric field ?

Ans :

(a) The force per unit charge is known as electric field

(b) N/C

177. Ramesh's aunt was housewife, she had a little knowledge of science. In a dark room when she pulled over a woollen sweater, she heard little crackles with tiny sparks. She became frightened and called Ramesh. Being a science student he explained the appropriate reason behind it with appropriate figure and than her aunt calmed down.



Transfer of charge

Due to a charge ,there a electric field is produce around a sphere.

(a) A hollow conducting sphere of radius 8 cm is given a charge of 16 μC. What is the electric field at the centre of the sphere?

(b) A hollow conducting sphere of radius 8 cm is given a charge of 16 μC. What is the electric field on the outer surface of the sphere?

Ans :

(a) Electric field at its centre = 0, because electric field at any point inside a hollow sphere is always zero.

(b) Electric field on the outer surface of the sphere is

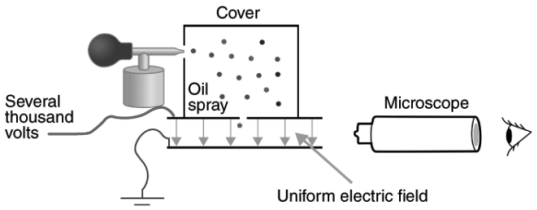
$$E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r^2}$$

$$= 9 \times 10^9 \times \frac{16 \times 10^{-6}}{(0.08)^2}$$

$$= 9 \times 10^9 \times \frac{16 \times 10^{-6}}{64 \times 10^{-4}}$$

$$= 2.25 \times 10^7 \text{ NC}^{-1}$$

178. In 1909, Robert Millikan and Harvey Fletcher conducted the oil drop experiment to determine the charge of an electron. They suspended tiny, charged droplets of oil between two metal electrodes by balancing downward gravitational force with upward drag and electric forces. The density of the oil was known, so Millikan and Fletcher could determine the droplets' masses from their observed radii (since from the radii they could calculate the volume and thus, the mass). Using the known electric field and the values of gravity and mass, Millikan and Fletcher determined the charge on oil droplets in mechanical equilibrium. By repeating the experiment, they confirmed that the charges were all multiples of some fundamental value. They calculated this value to be 1.5924×10^{-19} Coulombs (C), which is within 1% of the currently accepted value of 1.602×10^{-19} C. They proposed that this was the charge of a single electron.



(a) What was determined from Millikan's oil drop experiment?

(b) What is the currently accepted value of electric charge of an electron?

(c) How was the mass of an electron determined?

(d) Does an electron have mass?

(e) What was the conclusion of Millikan's oil drop experiment?

Ans :

(a) In 1909, Robert Millikan and Harvey Fletcher developed an experiment to determine the fundamental charge of the electron.

(b) 1.602×10^{-19} C.

(c) The mass of an electron determined by the calculation of density and Volume.

(d) Yes

(e) Electric charge is integral multiple of fundamental charge

179. The Gauss' theorem in electrostatics gives a relation between the electric flux through any closed hypothetical surface (called a Gaussian surface) and the charge enclosed by the surface. It states that the electric flux ϕ_E through any closed surface is equal to $1/\varepsilon_0$ times the net charge q enclosed by the surface. That is

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$$\phi_E = \oint \vec{E} \cdot d\vec{A} \frac{q}{\varepsilon_0}$$

where, ε_0 is permittivity of free space. This is the integral form of Gauss' theorem.

Gauss theorem is very useful in computing the electric fields due to a system of charges or symmetrical continuous distribution of charge.

(i) What is the unit of electric flux? If the unit of electrostatic field $\vec{E}$ is volt/meter.

(ii) A Gaussian surface is chosen to obtain an expression for the electric field at a point due to a given charge configuration. It is a closed surface. State one essential property of such a chosen Gaussian surface.

(iii) A large hollow metallic sphere has a positive charge of $35.4\,\mu C$ at its centre. Find how much electric flux emanates from the sphere.

(iv) What are the applications of Gauss' theorem?

(v) Is Gauss' law applicable only in the case of electric field?

Ans :

(i) The electric flux through a plane of area A, normal to an electrostatic field $\vec{E}$, is given by

$$\phi_E = EA$$

Unit of ϕ_E is (volt/metre) $\times$ metre^2 = volt-metre.

(ii) The gaussian surface should pass through the point at which electric field is required.

(iii) $q = 35.4\,\mu C = 35.4 \times 10^{-6}\,C$

As, $\phi_E = q/\varepsilon_0$

$$= \frac{35.4 \times 10^{-6}}{8.85 \times 10^{-12}}$$

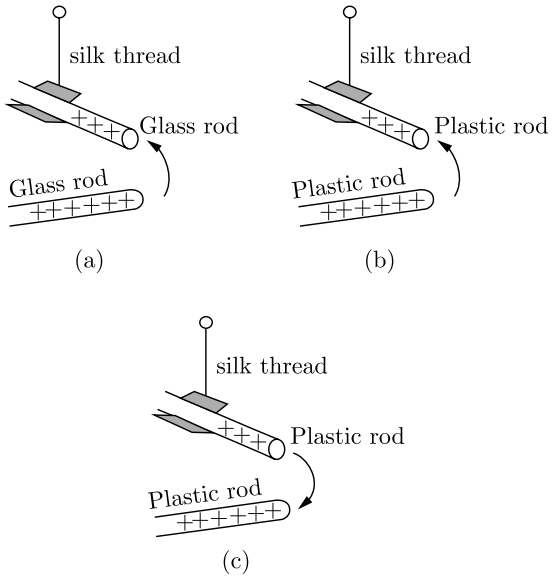
$$= 4 \times 10^6\,N - m^2/C$$

(iv) Gauss theorem is very useful in computing the electric fields due to a system of charges or symmetrical continuous distribution of charge.

(v) Gauss gave his law for the electric field only, but this rule is applicable in the case of the magnetic field also. In that case, magnetic flux lines are counted and the permittivity of the medium is replaced by the permeability of the medium. This law is also applicable for gravitational field.

180. When a glass rod is rubbed with silk, the rod acquires one kind of charge and the silk acquires the second kind of charge. This is true for any pair of objects that are rubbed to be electrified.

Now if the electrified glass rod is brought in contact with silk, with which it was rubbed, they no longer attract each other. They also do not attractor repel other light objects as they did on being electrified. Thus, the charges acquired after rubbing are lost when the charged bodies are brought in contact. What can you conclude from these observations? It just tells us that unlike charges acquired by the objects neutralise or nullify each other's effect. Therefore, the charges were named as positive and negative by the American scientist Benjamin Franklin. We know that when we add a positive number to a negative number of the same magnitude, the sum is zero. This might have been the philosophy in naming the charges as positive and negative. By convention, the charge on glass rod or cat's fur is called positive and that on plastic rod or silk is termed negative. If an object possesses an electric charge, it is said to be electrified or charged. When it has no charge it is said to be electrically neutral.



(a) When you charge a balloon by rubbing it on your hair this is an example of what method of charging?

(b) Which particle in an atom can you physically manipulate?

(c) If a negatively charged rod touches a conductor, the conductor will be charged by what method?

Ans :

(a) Frication

(b) Electrons

(c) Conduction

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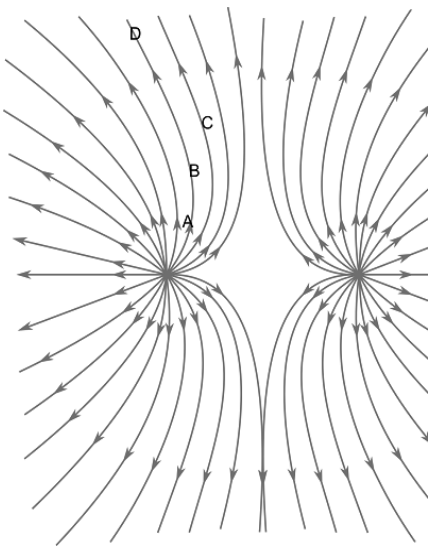
181. While travelling back to his residence in the car, Dr. Pathak was caught up in a thunderstorm. It became very dark. He stopped driving the car and waited for thunderstorm to stop. Suddenly he noticed a child walking alone on the road. He asked the boy to come inside the car till the thunderstorm stopped. Dr. Pathak dropped the boy at his residence. The boy insisted that Dr. Pathak should meet his parents. The parents expressed their gratitude to Dr. Pathak for his concern for safety of the child.

Answer the following questions based on the above information :

(a) Why is it safer to sit inside a car during a thunderstorm?

(b) Can charge be stored in a body?

(c) An electric field map is graphically expressed as shown in the figure. There are 4 indicated locations (A, B, C, and D) along one of the field lines. If a negative test charge is released at location B and free to move, in which way will it move toward?



Ans :

(a) It is safer to be inside a car during thunderstorm because the car acts like a Faraday cage. The metal in the car will shield you from any external electric fields and thus prevent the lighting from the travelling within the car.

(b) Yes, Charge can be stored in a capacitor, which is a combination of two conductors with something insulating (a dielectric) between them.

(c) A negative electric charge always seeks to travel in against the electric field direction or toward the positive charge, whereas a positive electric charge always goes in the electric field direction or towards the negative charge. It can be concluded from the preceding explanation that a negative test charge at location B in the figure attempts to move in against the electric field direction. Hence, the negative test charge moves towards point A.

182. Electrically, most of the materials can be placed in one of the two classes : conductors or insulators. Conductors are those, through which electric charge can easily flow.

Metals, human body, earth, mercury and electrolytes are conductors of electricity.

In metals, only the negative charges is free to move. Positive charge is immobile. The actual charge-carriers in metals are 'free electrons'. In metals, the outer electrons of the atoms leave the atoms and become 'free' to move throughout the volume of the metal. In electrolytes, both positive and negative charges move. The charges in an electrolyte are carried by ions and it is the ions that move in an electrolyte.

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Those substances in which electric charge cannot flow are called insulators (or dielectrics). Glass, hard-rubber, plastics and dry wood are insulators. Insulators have practically no free electrons.

An important difference between conductors and insulators is that when some charge is given to a conductor it readily gets transferred over its entire surface. On the other hand if some charge is given to an insulator it stays at the place where it is put on.

(i) A bird safely sits on a base high power transmission wire, while a man standing on the ground gets total shock on touching the same. Why?

(ii) Why the tyres of aircrafts are not made of ordinary rubber (which is an insulator) but of a special rubber which is slightly conducting why?

(iii) By which the currents are carried in conductors?

(iv) What is the major difference between the conductors and insulators?

(v) What is measured by the band gap between the valence band and conduction band?

Ans :

(i) The circuits between the bird sitting on the live wire and the earth is not complete due to which no current flows through the body of the bird and it remains safe. However, if a man standing on ground touches the same wire, the circuit to the earth is completed through his body and a heavy current passes through his body, earring a fatal shock.

(ii) The tyres of aircrafts are highly charged during landing due to friction between the tyres and the airstrip (earth). If the tyres are slightly conducting, the charge will not accumulate on them and will leak to the earth.

(iii) Conductor have lots of the free electrons that can carry electricity, if the potential difference is applied across them.

(iv) The major difference between the conductors and insulators is that when some charge is given to a conductor, it readily gets transferred over its entire, surface. On the other hand, if some charge is given to an insulator it stays at the place where it is put on.

(v) The more the band gap between the valence and conduction band the worse is the conduction of the material. For conductors, there are overlapping bands. So, conductors can carry electricity. But there is a huge energy gap in the case of insulators.

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CHAPTER 2

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Electric Potential and Capacitance

SUMMARY

1. ELECTROSTATIC POTENTIAL

The electric potential at any point in an electric field is defined as the work done in bringing a unit positive test charge from infinity to that point without acceleration.

If W is the work done in bringing infinitesimal positive test charge q_0 from infinity to given point, then electric potential,

$$V = \frac{W}{q_0}$$

Its SI unit is Volt V and its dimensional formula is $[ML^2T^{-3}A^{-1}]$.

2. POTENTIAL DIFFERENCE

The potential difference between two points in an electric field is defined as the work done in bringing unit positive charge from one point to another.

$$V_B - V_A = \frac{W_{AB}}{q_0}$$

Where, W_{AB} is work done in taking charge q_0 form A to B against of electrostatic force.

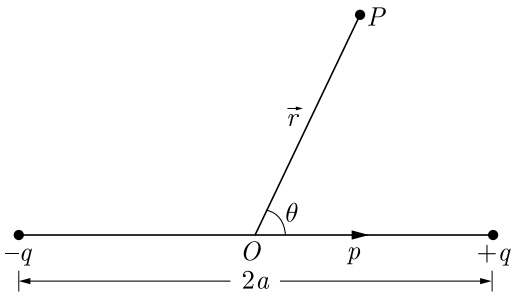
3. ELECTROSTATIC POTENTIAL DUE TO A POINT CHARGE

Electrostatic potential due to a point charge q at any point lying at a distance r from the origin, it is given by

$$V = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r}$$

4. ELECTROSTATIC POTENTIAL DUE TO AN ELECTRIC DIPOLE AT ANY POINT

Electrostatic potential due to an electric dipole at any point P whose position vector is r w.r.t. mid-point of dipole is given by



$$V = \frac{1}{4\pi\varepsilon_0} \cdot \frac{p\cos\theta}{r^2}$$

or $$V = \frac{1}{4\pi\varepsilon_0} \cdot \frac{\vec{p} \cdot \hat{r}}{|\vec{r}|^2}$$

Where, θ is the angle between r and p.

5. ELECTROSTATIC POTENTIAL DUE TO THIN CHARGED SPHERICAL SHALL

Electrostatic potential due to a thin charged spherical shell carrying charge q and radius R respectively, at any point P lying.

$$V_{\text{in}} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{R} \qquad \text{(Inside the shell)}$$

$$V_{\text{surface}} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{R} \qquad \text{(on the surface)}$$

$$V_{\text{out}} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{R} \qquad \text{(outside the shell)}$$

For $r > R$

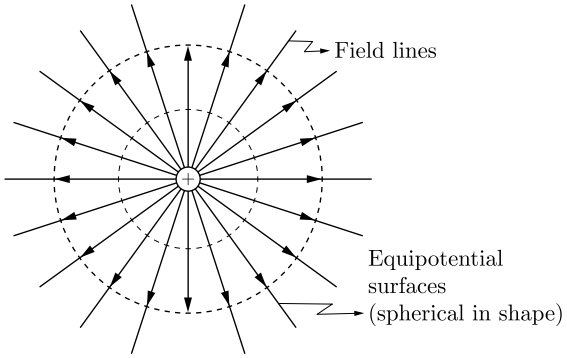
Where, r is the distance of point P from the centre of the shell.

6. EQUIPOTENTIAL SURFACE

A surface which have same electrostatic potential at every point on it is known as equipotential surface.

The shape of equipotential surface due to line charge is cylindrical.

Point charge is spherical as shown below:



Properties of Equipotential Surface

1. Equipotential surface do not intersect each other as it gives two directions of electric field E at intersecting point which is not possible.
2. Electric field is always normal to equipotential surface at every point of it and directly from one equipotential surface at higher potential to the equipotential surface at lower potential.
3. Work done in moving a test charge form one point of equipotential surface to other is zero.

The electric field at a point is related to the negative potential gradient as follows,

$$E = -\frac{dV}{dr}$$

i.e., $$E_X = -\frac{\partial V}{\partial x},$$

$$E_Y = -\frac{\partial V}{\partial y}$$

$$E_Z = -\frac{\partial V}{\partial z}$$

Where negative sign indicates that the direction of electric field is from higher potential to lower potential, i.e., in the direction of decreasing potential.

7. ELECTROSTATIC POTENTIAL ENERGY

The work done against electrostatic force gets stored as potential energy. This is called electrostatic potential energy.

i.e., $$\Delta U = U_B - U_A$$

$$= W_{AB}$$

The work done in moving a unit positive test charge over a closed path in an electric field is zero.

Thus, electrostatic forces are conservative in nature.

1. Electrostatic potential energy of a system of two point charges is given by

$$U = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{r}$$

Putting the values of charge with their signs.

2. Electrostatic potential of a system of n point charges is given by

$$U = \frac{1}{4\pi\varepsilon_0} \sum_{j=1}^{n} \sum_{i=1}^{n} \frac{q_j q_i}{r_{ji}} j \neq i \text{ and } ij = ji$$

8. POTENTIAL ENERGY IN AN EXTERNAL FIELD

Potential energy of a single charge q at a point with position vector r, in an external field is $qV(r)$, where $V(r)$ is the potential at the point due to external electric field E.

Potential Energy of a system of two charges in an external field.

$$U = q_1 V(r_1) + q_2 V(r_2) + \frac{q_1 q_2}{4\pi\varepsilon_0 r_{12}}$$

where,

q_1 and q_2 = two point charges at position vectors r_1 and r_2, respectively

$V(r_1)$ = potential at r_1 due to the external field

$V(r_2)$ = potential at r_2 due to the external field

Potential energy of an electric dipole in an uniform electric field

$$U = -pE\cos\theta$$

$$= \vec{p} \cdot \vec{E}, \text{ if } \cos\theta = 1$$

9. CAPACITANCE OF A CONDUCTOR

If charge q is given to an insulated conductor, it leads to increase its electric potential by V such that,

$$q \propto V \Rightarrow q = CV$$

Where, C is known as capacitance of a conductor. The capacitance depends on the shape, size and geometry of conductor, nature of surrounding medium and presence of other conductor in the neighbourhood of it.

Its SI unit is farad F.

Here, $$1 \text{ farad} = \frac{1 \text{ coulomb}}{1 \text{ volt}}$$

Farad is a very large unit of capacitance, So, μF is usually taken.

10. COMBINATION OF CAPACITORS

1. **Series Combination :** When capacitance are connected in series, then net capacitance C is given by

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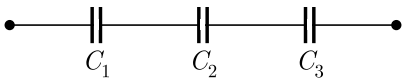


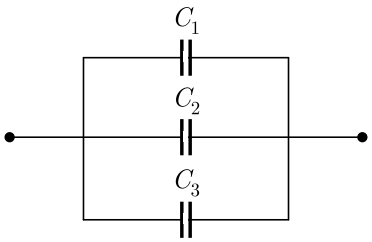
$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Net charge $Q = q_1 = q_2 = q_3$

(remain same)

Net potential difference $V = V_1 + V_2 + V_3$

2. **Parallel Combination :** When capacitors are connected in parallel, then the net capacitance is given by



$$C = C_1 + C_2 + C_3$$

In parallel combination net charge,

$$Q = q_1 = q_2 = q_3$$

Net potential difference,

$$V = V_1 = V_2 = V_3 \qquad \text{(remain same)}$$

11. CAPACITANCE OF PARALLEL PLATE CAPACITOR

A parallel plate capacitor consists of two parallel metallic plates separated by a dielectric. The capacitance of parallel plate capacitor is given by,

$$C = \frac{k\varepsilon_0 A}{d}$$

Where, K = dielectric constant

A = area of each plate

and d = separation between the plates

Special Cases :

1. When there is no medium between the plates, then $K = 1$

   So, $C_{\text{vaccum}} = \frac{\varepsilon_0 A}{d} = C_0$

2. When space between the plates is partly filled with a medium of thickness t and dielectric constant K, then capacitance

$$C = \frac{\varepsilon_0 A}{d - t + \frac{t}{K}} = \frac{\varepsilon_0 A}{d - t\left(1 - \frac{1}{K}\right)}$$

Clearly, $C > C_0$, i.e., on introduction slab between the plates of a parallel plate capacitor, its capacitance increases.

12. ENERGY STORED IN A CHARGED CAPACITOR

Energy stored in a charged capacitor is given by

$$U = \frac{1}{2}CV^2 = \frac{Q^2}{2C} = \frac{1}{2}QV \text{ joule}$$

This energy resides in the medium between the plates. The energy stored per unit volume of a charged capacitor is given by

$$u = \frac{U}{V} = \frac{1}{2}\varepsilon E^2 \text{ joule/m}^3$$

where, E is electric field strength.

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OBJECTIVE QUESTIONS

1. If the uniform electric field exists along X-axis,then equipotential is along

(a) XY-plane (b) XZ-plane

(c) YZ-plane (d) anywhere

Ans : **Main 2009**

Equipotential surface are planes in uniform electric field. So its lies in plane XY-plane.

Thus (a) is correct option.

2. Consider a point P on the perpendicular bisector dipole. At point P,

(a) electric field is zero.

(b) electric potential is zero.

(c) electric field is perpendicular to the axis of the dipole.

(d) Potential gradient is zero.

Ans : **Main 2010**

The electric potential on the perpendicular bisector or in the equatorial plane due to an electric dipole is zero as $\theta = 90^\circ$.

Thus (b) is correct option.

3. An electric dipole of moment $\vec{p}$ is placed in a uniform electric field $\vec{E}$. It has maximum (negative) potential energy when the angle between $\vec{p}$ and $\vec{E}$ is

(a) $\pi/2$ (b) zero

(c) π (d) $3\pi/2$

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Ans : **Main 2022 Sem-I**

When the angle between the dipole moment and electric field is 180°, then the potential energy of the electric dipole is maximum.

Thus (c) is correct option.

4. The electrostatic potential energy of two point charges, 1 μC each, placed 1 metre apart in air is

(a) 9×10^3 J (b) 9×10^9 J

(c) 9×10^{-3} J (d) 9×10^{-3} eV

Ans : **Main 2017**

The electric potential energy of two point charges 1 μC each, placed 1 metre apart in air is

$$U = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{r_{12}}$$
$$= 9 \times 10^9 \times \frac{10^{-6} \times 10^{-6}}{1}$$
$$= 9 \times 10^9 \times 10^{-12}$$
$$= 9 \times 10^{-3} \text{ J}$$

Thus (c) is correct option.

5. Electric potential at a point on the axial line of a short electric dipole is

(a) directly proportional to distance.

(b) inversely proportional to distance.

(c) inversely proportional to square of the distance.

(d) directly proportional to square of the distance.

Ans : **Main 2022 Sem-I**

Electric potential at a point on axial line by a short dipole is given by

$$V = \frac{\vec{p} \cdot \hat{r}}{4\pi\varepsilon_0 r^2} \Rightarrow V \propto \frac{1}{r^2}$$

Thus (c) is correct option.

6. Three point charges Q, Q and q are kept at the vertices A, B and C respectively of an equilateral triangle ABC having each side equal to a. Electrostatic potential energy of the system is zero. This is possible, if q is equal to

(a) Q (b) $Q/2$

(c) $-Q/2$ (d) $-Q/4$

Ans : **Main 2024**

Electrostatic potential energy due to a system of three charges is given by

$$U = k\left(\frac{q_1 q_2}{r_{12}} + \frac{q_1 q_3}{r_{13}} + \frac{q_2 q_3}{r_{23}}\right)$$
$$0 = k\left(\frac{Q^2}{a} + \frac{Qq}{a} + \frac{Qq}{a}\right)$$
$$-\frac{Q^2}{a} = \frac{2Qq}{a}$$
$$q = -\frac{Q}{2}$$

Thus (c) is correct option.

7. Consider 10 identical capacitors each of capacitance 5 μF. The ratio of the minimum and the maximum possible values of the capacitance that can be obtained from them is

(a) 1 : 50 (b) 1 : 100

(c) 50 : 1 (d) 100 : 1

Ans : **Main 2022 Sem-I**

Minimum capacitance $= \frac{1}{10} \times 5 = \frac{1}{2}$ μF

Maximum capacitance $= 10 \times 5 = 50$ μF

Ratio of minimum to maximum value of capacitance

$$= \frac{\frac{1}{2}}{50} = \frac{1}{100} \text{ or } 1 : 100$$

Thus (b) is correct option.

8. The capacitance of a parallel plate capacitor does not depend on

(a) area of each plate

(b) potential difference between the two plates

(c) nature of the medium between the two plates

(d) distance between the two plates

Ans : **Main 2025 Sem-I**

Parallel plate capacitance

$$C = \frac{\varepsilon_0 A}{d}$$

Where A = Area of plates

d = distance between the plates

Hence of capacitance of parallel plate capacitor does not depends on the potential difference between plates

Thus (b) is correct option.

9. Two plates of a parallel plate capacitor are 1 cm apart and potential difference between them is 10 V. The electric field between the plates is

(a) 10 N-C^{-1} (b) 250 N-C^{-1}

(c) 500 N-C^{-1} (d) 1000 N-C^{-1}

Ans : **Main 2013**

Given,

Distance between plates,

$$d = 1\text{cm} = 0.01 \text{ m}$$

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and potential difference between them,

$$V = 10 \text{ Volt}$$

electric field between the plates in a parallel plate capacitor,

$$E = \frac{V}{d} = \frac{10}{0.01}$$
$$= 1000 \text{ N-C}^{-1}$$

Thus (d) is correct option.

10. The capacitance of a parallel plate capacitor ..... by the introduction of a dielectric between the plates of capacitor.

(a) increases

(b) decreases

(c) remains same

(d) nothing can be said

Ans : SQP 2010

When vacuum is present between the plates of capacitor, then capacitance of parallel plate is given by,

$$C = \frac{\varepsilon_0 A}{d} \quad ...(1)$$

If a medium of dielectric strength K is introduced between the plate of capacitor then,

Capacitance, $C' = \frac{K\varepsilon_0 A}{d}$ [From equation (1)]

$$C' = KC$$

i.e. capacitance increase K time.

Thus (a) is correct option.

11. The electric potential due to a small electric dipole at a large distance r from the center of the dipole is proportional to

(a) r (b) $\frac{1}{r}$

(c) $\frac{1}{r^2}$ (d) $\frac{1}{r^3}$

Ans : SQP 2018, 2016

Electric potential at an axial point of a dipole is given by,

$$V = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^2 - a^2}$$

where, p = Electric dipole moment

r = Distance of axial point from the center of dipole

$2a$ = Length of the dipole

For large distance $r^2 >>> a^2$,

$$V = \frac{p}{4\pi\varepsilon_0 r^2}$$

Hence, $V \propto \frac{1}{r^2}$

Thus (c) is correct option.

12. The ratio of charge to potential of a capacitor is known as its

(a) capacitance (b) conductance

(c) inductance (d) resistance

Ans : Main 2017

Capacitance of a capacitor,

$$C = \frac{q}{V}$$

It is also called electrostatic capacity of the capacitor.

where, q = charge,

and V = potential of the capacitor

Thus (a) is correct option.

13. The energy stored in a capacitor is actually stored

(a) between the plates

(b) on the positive plate

(c) on the negative plate

(d) on the outer surfaces of the plates

Ans : Main 2014

The energy stored in a capacitor is in the form of electrostatic energy. It is actually stored between the plates of the capacitor.

Thus (a) is correct option.

14. Two capacitors of capacitance 3 μF and 6 μF are connected in a series combination. Their equivalent capacitance will be

(a) 2 μF (b) 3 μF

(c) 6 μF (d) 9 μF

Ans : Main 2024, 2005

Here,

Capacitance of first capacitor,

$$C_1 = 3\,\mu\text{F}$$

and capacitance of second capacitor,

$$C_2 = 6\,\mu\text{F}$$

Equivalent capacitance of the capacitors in series combination,

$$C_{eq} = \frac{C_1 \times C_2}{C_1 + C_2}$$
$$= \frac{3 \times 6}{3 + 6} = 2\,\mu\text{F}$$

Thus (a) is correct option.

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15. Three capacitors of capacitances $2\,\mu F$, $4\,\mu F$ and $6\,\mu F$ are connected in a parallel combination. Their equivalent capacitance will be

(a) $2\,\mu F$ (b) $4\,\mu F$

(c) $6\,\mu F$ (d) $12\,\mu F$

Ans : SQP 2016

Here,

Capacitance of first capacitor, $C_1 = 2\,\mu F$

Capacitance of second capacitor, $C_2 = 4\,\mu F$

Capacitance of third capacitor $C_3 = 6\,\mu F$

The equivalent capacitance of the capacitors in parallel combination,

$$C_{eq} = C_1 + C_2 + C_3$$
$$= 2 + 4 + 6$$
$$= 12\,\mu F$$

Thus (d) is correct option.

16. A parallel plate capacitor is made by stacking n equally spaced plates connected alternatively. If capacitance between any two adjacent plates is C, then the resultant capacitance is

(a) C (b) nC

(c) $(n-1)C$ (d) $(n+1)C$

Ans : SQP 2004

Number of plates $= n$ and capacitance between any two adjacent plates $= C$. We know that as n plates are joined alternatively.

Therefore, no. of capacitors $= (n-1)$.

Thus resultant capacitance of parallel plate capacitor,

$$C' = (n-1)C$$

Thus (c) is correct option.

17. An infinite number of capacitors with capacitances $1\,\mu F$, $\frac{1}{2}\,\mu F$, $\frac{1}{4}\,\mu F$, $\frac{1}{8}\,\mu F$, ... etc. are connected in parallel combination. Their equivalent capacitance will be

(a) $8\,\mu F$ (b) $6\,\mu F$

(c) $4\,\mu F$ (d) $2\,\mu F$

Ans : Main 2015

Capacitance of infinite number of capacitors,

$$C_1 = 1\,\mu F,\ C_2 = \frac{1}{2}\,\mu F,\ C_3 = \frac{1}{4}\,\mu F,$$

$$C_4 = \frac{1}{8}\,\mu F, \text{ ... etc.}$$

Equivalent capacitance of infinite capacitors in parallel combination,

$$C_{eq} = C_1 + C_2 + C_3 + C_4 + \text{ ... upto } \infty$$
$$= 1 + \frac{1}{2} + \frac{1}{4} + \frac{1}{8} + \text{ ... upto } \infty$$
$$= \frac{1}{1-\left(\frac{1}{2}\right)} = 2\,\mu F$$

Thus (d) is correct option.

18. The electrostatic energy stored in a capacitor is

(a) $\frac{1}{2}QV$ (b) $\frac{1}{QV}$

(c) $\frac{2}{QV}$ (d) QV

Ans : Main 2024, 2009

Electrostatic energy stored in a capacitor,

$$U = \frac{1}{2} \times CV^2$$
$$= \frac{1}{2} \times \frac{Q}{V} \times V^2 = \frac{1}{2}QV$$

where, Q = Charge,

V = Potential

and C = Capacity of the capacitor

Thus (a) is correct option.

19. A parallel plate capacitor is first charged and then a dielectric slab is introduced between the plates. The quantity that remains unchanged is

(a) charge (b) energy

(c) potential (d) capacitance

Ans : SQP 2004

When a dielectric slab is introduced between the plates of a charged parallel plate capacitor, the charge remains unchanged.

Thus (a) is correct option.

20. A $10\,\mu F$ capacitor is charged by a battery of e.m.f. 100 V. The electrostatic energy stored in the capacitor is

(a) 0.5 J (b) 0.05 J

(c) 0.5 mJ (d) 0.05 mJ

Ans : SQP 2012

Capacitance of the capacitor,

$$C = 10\,\mu F$$
$$= 10 \times 10^{-6}\,F$$

and voltage of the battery,

$$V = 100\,\text{Volt}$$

electrostatic energy stored in the capacitor,

$$U = \frac{1}{2} \times CV^2$$
$$= \frac{1}{2} \times (10 \times 10^{-6}) \times (100)^2 = 0.05\,J$$

Thus (b) is correct option.

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21. A $4\,\mu F$ capacitor is charged to 400 V. If its plates are joined through a resistance, then heat produced in the resistance will be

(a) 0.16 J (b) 0.32 J

(c) 0.64 J (d) 1.28 J

Ans : **Main 2014**

Capacitance of the capacitor,

$$C = 4\,\mu F$$
$$= 4 \times 10^{-6}\,F$$

Voltage, $V = 400$ Volt

Heat produced in the resistance

= Electrical energy stored in the capacitor

$$= \frac{1}{2} \times CV^2$$
$$= \frac{1}{2} \times (4 \times 10^{-6}) \times (400)^2$$
$$= 0.32\,J$$

Thus (b) is correct option.

22. A parallel plate capacitor having a plate separation of 2 mm is charged by connecting it to a 300 V supply. The energy density is

(a) $0.01\,J\text{-}m^{-3}$ (b) $0.1\,J\text{-}m^{-3}$

(c) $1.0\,J\text{-}m^{-3}$ (d) $10\,J\text{-}m^{-3}$

Ans : **Main 2008**

Given,

Distance between the plates,

$$d = 2\,mm = 2 \times 10^{-3} m$$

Supply voltage, $V = 300$ Volt

The energy density of a parallel plate capacitor,

$$E = \frac{1}{2}\varepsilon_0 \frac{V^2}{d^2}$$
$$= \frac{1}{2} \times (8.854 \times 10^{-12}) \times \frac{(300)^2}{(2 \times 10^{-3})^2}$$
$$= 0.1\,J\text{-}m^{-3}$$

where, ε_0 = Absolute electric permittivity of free space equal to $8.854 \times 10^{-12}\,C^2\text{-}N^{-1}\text{-}m^{-2}$

Thus (b) is correct option.

23. When two charged capacitors having capacitance and potential C_1, V_1 and C_2, V_2 respectively, are joined with the help of a wire, the common potential will be

(a) $C_1 + C_2$ (b) $\frac{C_1V_1 + C_2V_2}{C_1 + C_2}$

(c) $\frac{C_1V_1 + C_2V_2}{V_1 + V_2}$ (d) $\frac{C_1V_1^2 + C_2V_2^2}{V_1^2 + V_2^2}$

Ans : **SQP 2025**

Capacitance of first capacitor $= C_1$

Potential of first capacitor $= V_1$

Capacitance of second capacitor $= C_2$

and Potential of second capacitor $= V_2$

When two charged capacitors are joined with the help of a wire, then the common potential,

$$V = \frac{C_1V_1 + C_2V_2}{C_1 + C_2}$$

Thus (b) is correct option.

24. Two capacitors of capacitances $3\,\mu F$ and $6\,\mu F$ are charged to a potential of 12 V each. They are now connected to each other, with the positive plate of each joined to the negative plate of the other. The potential difference across each capacitor will be

(a) 6 V (b) 4 V

(c) 3 V (d) Zero

Ans : **SQP 2017, 2015**

Capacitance of first capacitor, $C_1 = 3\,\mu F$

Capacitance of second capacitor, $C_2 = 6\,\mu F$

Potential difference, $V = 12$ Volt

When the capacitors are connected to each other with the positive plate of each joined to the negative plate of the other, then the potential difference across each capacitor will be zero.

Thus (d) is correct option.

25. A sheet of aluminium foil of negligible thickness is introduced between the plates of a capacitor. The capacitance of the capacitor

(a) increases

(b) decreases

(c) becomes infinite

(d) remains unchanged

Ans : **SQP 2006**

When a sheet of conducting metal of negligible thickness is introduced between the plates of a capacitor, the capacitance of the capacitor remains unchanged.

Since the sheet of aluminium foil of negligible thickness is a sheet of the conducting metal, therefore the capacitance of the capacitor remains unchanged.

Thus (d) is correct option.

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26. A parallel plate capacitor with oil between the plates (dielectric constant of oil $K=2$) has a capacitance C. If the oil is removed, then capacitance of the capacitor becomes

(a) $\sqrt{2}C$ (b) $2C$

(c) $\frac{C}{\sqrt{2}}$ (d) $\frac{C}{2}$

Ans : Main 2009

Dielectric constant of oil, $K = 2$

and Capacitance with oil $= C$

Capacitance of the capacitor with oil,

$$C = KC_0 = 2C_0$$

$$C_0 = \frac{C}{2}$$

where, $C_0 =$ Capacitance of the capacitor after oil is removed.

Thus (d) is correct option.

27. If a copper plate of thickness b is inserted a parallel plate capacitor, then its new capacity will be (where d = Distance between plates)

(a) $\frac{\varepsilon_0 A}{d+b}$ (b) $\frac{\varepsilon_0 A}{d-b}$

(c) $\frac{\varepsilon_0 A}{2d-b}$ (d) $\frac{2\varepsilon_0 A}{2d-b}$

Ans : SQP 2004

Thickness of copper plate $= b$

and Distance between the plates $= d$

As the copper plate is a conducting slab, therefore capacity of the capacitor with copper plate,

$$C = \frac{\varepsilon_0 A}{d-t} = \frac{\varepsilon_0 A}{d-b}$$

Thus (b) is correct option.

28. Which of the following ratios is constant for an isolated conductor?

(a) $\frac{\text{Total charge}}{\text{Potential}}$

(b) $\frac{\text{Charge added}}{\text{Potential difference}}$

(c) $\frac{(\text{Total charge})^2}{\text{Potential}}$

(d) none of these

Ans : Main 2010, 2013

Capacitance of isolated conductor is given by,

Capacitance, $C = \frac{\text{Total charge}\,(Q)}{\text{Potential}\,(V)}$

Capacitance is constant for a conductor.

Thus (a) is correct option.

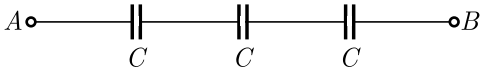
29. Three capacitors each of capacity C are connected in series. The resultant capacity will be

(a) $3C$ (b) $3/C$

(c) $C/3$ (d) $1/3C$

Ans : Main 2017

According to the question,we can drwa



Resultant capacity is given by,

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$= \frac{1}{C} + \frac{1}{C} + \frac{1}{C}$$

$$C_{eq} = C/3$$

Thus (c) is correct option.

30. A parallel plate air capacitor is charged to a potential difference of V. If distance between the plates is increased, then potential difference between the plates

(a) decreases (b) increases

(c) becomes zero (d) does not change

Ans : SQP 2010

Initial potential difference of capacitor,

$$V_1 = V$$

Charge on the plates of a parallel plate air capacitor always remains constant after increasing or decreasing the distance between the plate.

i.e., $Q =$ Constant

Capacitance of a parallel plate capacitor,

$$C = \frac{\varepsilon_0 A}{d}$$

Charge on the plates of capacitor,

$$Q = CV = \frac{\varepsilon_0 A}{d} \times V$$

$$V \propto d$$

Since distance between the plates is increases, therefore potential difference V between the plates also increases.

Thus (b) is correct option.

31. The electrostatic capacity of a capacitor depends upon its

(a) charge (b) potential

(c) resistance (d) both a and b

Ans : SQP 2009

Electrostatic capacity of a capacitor,

$$C = \frac{q}{V}$$

NODIA

It is also called capacitance of the capacitor.

Where, q = charge,

and V = potential of the capacitor

Thus (d) is correct option.

32. If 125 water drops of equal radius and equal capacitance C, coalesce to form a single drop of capacitance C' the relation between C and C' is

(a) $C' = C$ (b) $C' = 5C$

(c) $C' = 125C$ (d) $C' = 250C$

Ans : **Main 2012**

Given,

Number of water drops $n = 125$

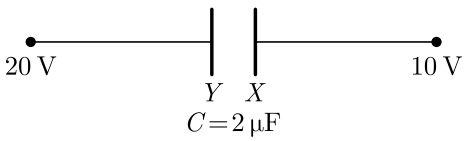
Capacitance of each water drop $= C$

If n small drops, each of capacitance C, coalesce to form a big drop, then capacitance of the big drop,

$$C' = n^{1/3} \times C$$
$$= (125)^{1/3} \times C$$
$$= 5C$$

Thus (b) is correct option.

33. The charge on plate X in the given figure



(a) $20\,\mu C$ (b) $-20\,\mu C$

(c) zero (d) $-10\,\mu C$

Ans : **Main 2011**

Capacitance, $C = \dfrac{\text{Charge}\,(Q)}{\text{Potential}\,(V)}$

$Q = CV$

Here, $C = 2\,\mu F = 2 \times 10^{-6}\,F$

$V = 20 - 10 = 10$ Volt

Now, $Q = 2 \times 10^{-6} \times 10$

$Q = 20 \times 10^{-6} = 20\,\mu C$

In the capacitor charge on Y plate is $20\,\mu C$ and the charge on X-plate is $-20\,\mu F$.

Thus (b) is correct option.

34. The capacitance of an isolated spherical conductor of radius 15 cm is

(a) $1.7 \times 10^{-11}\,F$ (b) $3.4 \times 10^{-11}\,F$

(c) $5.1 \times 10^{-11}\,F$ (d) $6.8 \times 10^{-11}\,F$

Ans : **SQP 2016**

Radius of spherical conductor,

$r = 15\,cm = 0.15\,m$

Capacitance of an isolated spherical conductor,

$$C = 4\pi\varepsilon_0 r$$
$$= \frac{1}{9 \times 10^9} \times 0.15$$
$$= 1.7 \times 10^{-11}\,F$$

where, $\dfrac{1}{4\pi\varepsilon_0} = 9 \times 10^9\,N\text{-}m^{-2}\text{-}C^{-2}$

Thus (a) is correct option.

35. The earth is a spherical conductor of radius 6.4×10^6 m. Its capacitance is

(a) $7.11 \times 10^4\,F$ (b) $7.11 \times 10^{-4}\,F$

(c) $7.11 \times 10^5\,F$ (d) $7.11 \times 10^{-5}\,F$

Ans : **Main 2004, 2002**

Radius of earth,

$r = 6.4 \times 10^6\,m$

Capacitance of earth as spherical conductor,

$$C = 4\pi\varepsilon_0 r$$
$$= \frac{1}{9 \times 10^9} \times (6.4 \times 10^6)$$
$$= 7.11 \times 10^{-4}\,F$$

where, $\dfrac{1}{4\pi\varepsilon_0} = 9 \times 10^9\,N\text{-}m^{-2}\text{-}C^{-2}$

Thus (b) is correct option.

36. The equipotential surfaces of a uniform electric filed E are planes parallel to the YZ-plane.

(i) What is the direction of the electric field E ?

(a) The electric field is along X-axis

(b) The electric field is along Y-axis

(c) The electric field is along Z-axis

(d) The electric field is along negative Y-axis.

(ii) An electric dipole with its charges $-q$ and $+q$, located at the points $(0, -l, 0)$ and $(0, +l, 0)$ lies in this field. Magnitude of the torque acting on the dipole is

(a) qlE (b) $2qlE$

(c) $4qlE$ (d) $8qlE$

Ans : **Main 2022 Sem-I**

(i) (a)

(ii) (b) Torque

$$(\tau) = pE\sin\theta$$
$$= q \cdot 2lE \quad (\theta = 90^\circ, p = q \cdot 2l)$$
$$= 2qlE$$

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37. 64 identical drops each of capacity of $5\,\mu F$ combine to form a big drop. What is the capacity of big drop?

(a) $25\,\mu F$ (b) $4\,\mu F$

(c) $164\,\mu F$ (d) $20\,\mu F$

Ans : Main 2016, 2015, 2013

Capacitance of spherical conductor is given by,

$$C_s = 4\pi\varepsilon_0 r$$

$$5 = 4\pi\varepsilon_0 r \text{ (for small drop)} \quad ...(1)$$

When small drops combine to form a big drop than volume remains constant,

Big drop volume $= 64 \times$ One small drop volume

$$\frac{4}{3}\pi R^3 = 64 \times \frac{4}{3}\pi r^3$$

$$R = 4r \quad ...(2)$$

$$C_B = 4\pi\varepsilon_0 R$$

where, $R =$ radius of big drop

$$C_B = 4\pi\varepsilon_0(4r) \quad \text{[From equation (2)]}$$

$$C_B = 4(4\pi\varepsilon_0 r) \quad ...(3)$$

Dividing equation (1) by (2), we get

$$\frac{5}{C_B} = \frac{4\pi\varepsilon_0 r}{4(4\pi\varepsilon_0 r)}$$

$$C_B = 5 \times 4 = 20\,\mu F$$

Thus (d) is correct option.

38. If an uncharged capacitor is charged by connecting it to a battery, then the amount of energy lost as heat is

(a) QV (b) QV^2

(c) $\frac{1}{2}QV$ (d) $\frac{1}{2}QV^2$

Ans : Main 2017, 2012

Charge given to the capacitor by a battery,

$$Q = CV$$

and work done by the battery,

$$W = QV$$

Energy stored in the capacitor,

$$U = \frac{1}{2}CV^2$$

$$= \frac{1}{2}VC \cdot V = \frac{1}{2}QV$$

Therefore,

Energy lost as heat = Work done − Energy stored

$$U' = QV - \frac{1}{2}QV = \frac{1}{2}QV$$

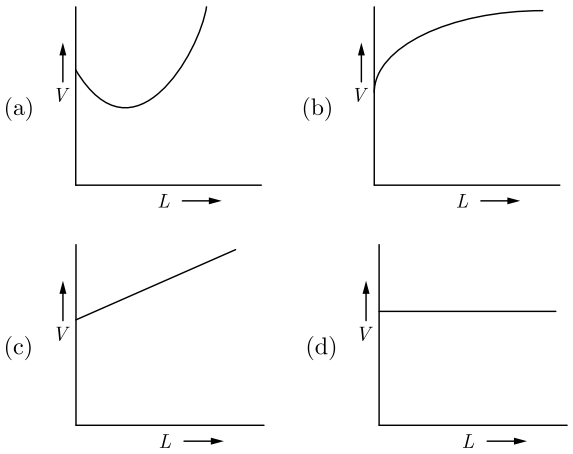
where, $Q =$ Charge,

$V =$ Potential

and $C =$ Capacity of the capacitor

Thus (c) is correct option.

39. A dielectric plate is inserted between plates of a parallel plate capacitor, to fill the space between the plates. The capacitor is charged and later disconnected from the battery. Now the dielectric plate is slowly withdrawn from the capacitor. The graph of potential difference V across the plates and the length of the dielectric plate L with drawn is



Ans : Main 2005

Potential difference across a parallel plate capacitor,

$$V = \frac{qd}{\varepsilon_0 \kappa A} \propto \frac{1}{\kappa}$$

Therefore as the dielectric plate is taken out, this potential difference increases.

And it becomes constant when the dielectric plate is completely removed.

Therefore the graph of potential difference V across the plates and length of the dielectric plate L will be as shown in option (b).

Thus (b) is correct option.

40. A spherical drop of capacitance $1\,\mu F$ is broken into eight drops of equal radius. The capacitance of each small drop is

(a) $\frac{1}{2}\,\mu F$ (b) $\frac{1}{4}\,\mu F$

(c) $\frac{1}{8}\,\mu F$ (d) $\frac{1}{16}\,\mu F$

Ans : SQP 2010

Capacitance of big drop, $C_1 = 1\,\mu F$

Number of small drops, $n = 8$

Since volume of big drop remains the same after it is broken into eight small drops,

NODIA

Therefore, $\frac{4}{3}\pi R^3 = 8 \times \frac{4}{3}\pi r^3$

$$R = 2r$$

where, $R =$ Radius of big drop

and $r =$ Radius of small drop

Capacitance of the spherical drop,

$$C = 4\pi\varepsilon_0 r$$

$$C \propto r$$

Therefore, $\frac{C_1}{C_2} = \frac{R}{r} = \frac{2r}{r} = 2$

or $C_2 = \frac{C_1}{2} = \frac{1}{2}\,\mu F$

where, $C_2 =$ Capacitor of each small drop

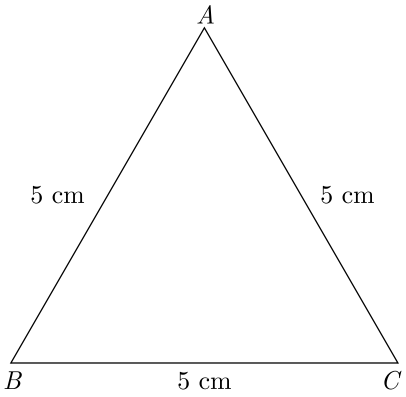
Thus (a) is correct option.

41. Three equal charges of 5.0 μC each, are placed at the three vertices of an equilateral triangle of side 5.0 cm each. The electrostatic potential energy of the system of charges is

(a) 13.5 J (b) 17.5 J

(c) 27 J (d) 15 J

Ans : Main 2022 Sem-I



$$U = \frac{kq^2}{5\times10^{-2}} + \frac{kq^2}{5\times10^{-2}} + \frac{kq^2}{5\times10^{-2}}$$

$$= \frac{k}{5\times10^{-2}}\left[(5)^2 + (5.0)^2 + (5.0)^2\right] \times 10^{-12}$$

$$= \frac{3\times9\times10^9\times25\times10^{-12}}{5\times10^{-2}} = 13.5\,J$$

Thus (a) is correct option.

42. A capacitor of capacitance 10 μF is charged to a potential difference of 1000 V.

(i) Electrostatic potential energy stored in the capacitor is

(a) 0.005 J (b) 0.25 J

(c) 0.5 J (d) 5.0 J

(ii) If a slab of dielectric constant $K = 5$ is introduced between its two plates in order to occupy the space completely, capacitance of the capacitor becomes

(a) 2 μF (b) 10 μF

(c) 50 μF (d) 100 μF

Ans : Main 2022 Semi

(i) (d) 5.0 J

Electrostatic potential energy

$$E = \frac{1}{2}CV^2$$

$$= \frac{1}{2}\times10\times10^{-6}\times(1000)^2$$

$$= 5\,J$$

(ii) (c) 50 μF

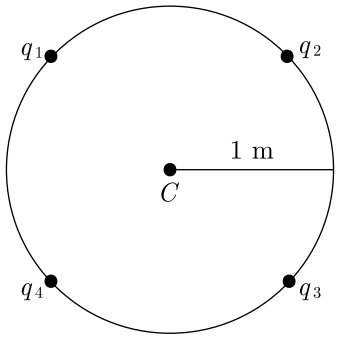
Initially, $C_0 = 10\,\mu F$

After inserting a slab,

$$C' = C_0 K$$

$$= 10 \times 5 = 50\,\mu F$$

43. Three charges $q_1 = 3\,\mu F$, $q_2 = 4\,\mu F$ and $q_3 = -7\,\mu F$ are placed on the circumference of a circle of radius 1.0 m as shown in the figure below. What is the value of charge q_4 placed on the same circle, if the potential at the centre, $V_0 = 0$?



(a) – 4 μF (b) $-3\,\mu F$

(c) 7 μF (d) 0

Ans : Main 2022 Sem-I

According to superposition principle, total potential at the centre O will be given by

$$V = V_1 + V_2 + V_3 + V_4$$

$$V = (kq_1/1) + (kq_2/1) + (kq_3/1) + (kq_4/1)$$

$$V = k(q_1 + q_2 + q_3 + q_4)/1$$

$$V = 0 \quad \text{(given)}$$

$$0 = k(q_1 + q_2 + q_3 + q_4)/1$$

$$(0\times1)/k = q_1 + q_2 + q_3 + q_4$$

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$$0 = 3\,\mu C + 4\,\mu C - 7\,\mu C + q_4$$
$$0 = 7\,\mu C - 7\,\mu C + q_4$$
$$0 = 0 + q_4$$
$$q_4 = 0$$

Thus (d) is correct option.

44. A point charge q is kept at each of the vertices of an equilateral triangle having each side a. Total electrostatic potential energy of the system is

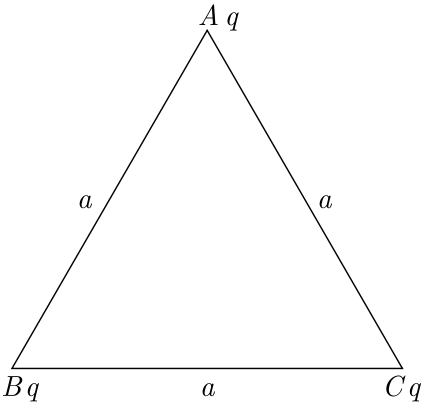
(a) $\left(\frac{1}{4\pi\varepsilon_0}\right)\frac{3q^2}{a^2}$ (b) $\left(\frac{1}{4\pi\varepsilon_0}\right)\frac{3q}{a}$

(c) $\left(\frac{1}{4\pi\varepsilon_0}\right)\frac{3q^2}{a}$ (d) $\left(\frac{1}{4\pi\varepsilon_0}\right)\frac{3q}{a^2}$

Ans : Main 2020, 2018

Potential energy

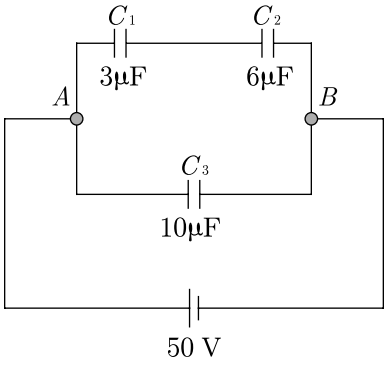
$$U = \frac{1}{4\pi\varepsilon_0}\left[\frac{q^2}{a} + \frac{q^2}{a} + \frac{q^2}{a}\right]$$



$$= \frac{1}{4\pi\varepsilon_0}\cdot\frac{3q^2}{a}$$

Thus (c) is correct option.

45. Three capacitors $C_1 = 3\,\mu F$, $C_2 = 6\,\mu F$ and $C_3 = 10\,\mu F$ are connected to a 50 V battery as shown in the figure below.



The equivalent capacitance of the circuit between point A and B and the charge on C_1 are.

(a) 12 μF, 150 μC

(b) 4.75 μF, 100 μC

(c) 12 μF, 100 μC

(d) 4.75 μF, 150 μC

Ans : Main 2022 Sem-I

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{3} + \frac{1}{6}$$
$$C_{eq} = 2\,\mu F$$

C_{eq} is in parallel with C_3, hence equivalent capacitance of the circuit between points A and B will be $10 + 2 = 12\,\mu F$

Charge on $C_1 = q_1 = (C_{eq})(V)$
$$= (2\,\mu F)(50\,V) = 100\,\mu C$$

Thus (c) is correct option.

46. Three capacitors, each of capacitance C, are connected in series. Their equivalent capacitance is C_s. The same three capacitors are now connected in parallel. Their equivalent capacitance becomes C_p. The ratio of C_p to C_s is

(a) 9 : 1 (b) 1 : 9

(c) 3 : 1 (d) 1 : 3

Ans : Main 2022 Sem-I

Three capacitors are in series

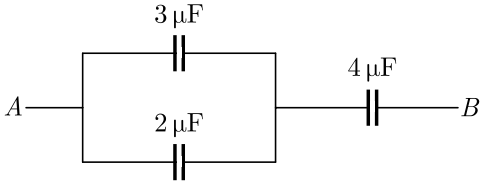
$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$
$$\frac{1}{C_s} = \frac{1}{C} + \frac{1}{C} + \frac{1}{C}$$
$$\frac{1}{C_s} = \frac{3}{C}$$
$$C_s = \frac{C}{3}$$

Three capacitors are in parallel

$$C_p = C_1 + C_2 + C_3$$
$$= C + C + C = 3C$$
$$\text{Ratio} = \frac{C_p}{C_s} = \frac{3C}{\frac{C}{3}} = \frac{9C}{C} = 9:1$$

Thus (a) is correct option.

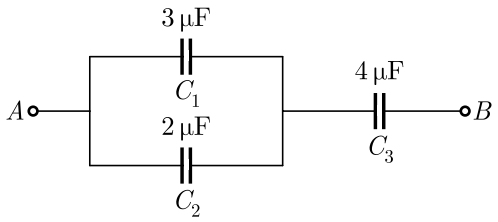
47. The equivalent capacity between A and B is



(a) $\frac{20}{9}\,\mu F$ (b) $9\,\mu F$

(c) $1\,\mu F$ (d) $\frac{1}{9}\,\mu F$

Ans : **Main 2013**



In the given circuit C_1 and C_2 are connected in parallel combination Hence, equivalent capacitance,

$$C' = C_1 + C_2$$
$$= 3 + 2 = 5\,\mu F$$

C' and C_3 are connected in series combination Now, equivalent capacitance between A and B,

$$C_{AB} = \frac{C' \times C_3}{C' + C_3}$$
$$= \frac{5 \times 4}{5 + 4} = \frac{20}{9}\,\mu F$$

Thus (a) is correct option.

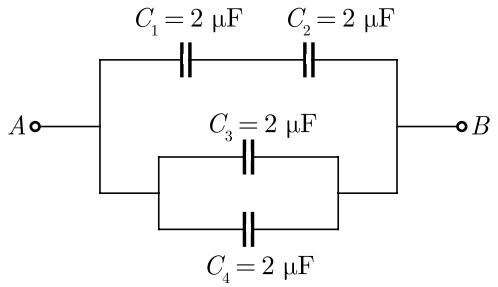
48. Minimum number of capacitors of $2\,\mu F$ each required to obtain a capacitance of $5\,\mu F$ will be

(a) 4 (b) 3

(c) 5 (d) 6

Ans : **Comp 2018**

To obtain a equivalent capacitance of $5\,\mu F$, we will arranged the capacitor as shown in the figure.



In the circuit diagram C_1 and C_2 are connected in series combination.

Hence, Equivalent capacitance,

$$\frac{1}{C'} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{2} + \frac{1}{2}$$
$$C' = 1\,\mu F$$

C_2 and C_3 capacitors are connected in parallel combination.

Hence, Equivalent capacitance,

$$C'' = C_3 + C_4$$
$$= 2 + 2 = 4\,\mu F$$

C' and C'' are connected in parallel combination Hence, Total equivalent capacitance,

$$C_{eq} = C' + C''$$
$$= 1 + 4 = 5\,\mu F$$

Hence, four capacitors are required to obtain equivalent capacitance of $5\,\mu F$.

Thus (a) is correct option.

49. A parallel plate capacitor of plate area $A = 600\,cm^2$and plate separation $d = 2.0$ mm is connected to DC

source of 200 V.

(i) What is the magnitude of the uniform electric field E between the plates?

(a) $E = 1.0 \times 10^5\,V/m$

(b) $E = 1.0 \times 10^7\,V/m$

(c) $E = 0.5 \times 10^5\,V/m$

(d) $E = 0.5 \times 10^7\,V/m$

(ii) What is the charge density a on any one of the two plates?

(a) $\sigma = 8.85 \times 10^{-7}\,C/m^2$

(b) $\sigma = 8.85 \times 10^{-9}\,C/m^2$

(c) $\sigma = 4.45 \times 10^{-7}\,C/m^2$

(d) $\sigma = 4.45 \times 10^{-9}\,C/m^2$

Ans : **Main 2022 Sem-I**

(i) (a) $E = 1.0 \times 10^5\,V/m$

$$A = 600\,cm^2$$
$$= 600 \times 10^{-4}\,m^2$$
$$d = 2.0\,mm$$
$$V = 200\,Volt$$
$$E = V/d$$
$$= \frac{200\,V}{0.002\,m} = 1 \times 10^5\,V/m$$

(ii) (a) $\sigma = 8.85 \times 10^{-7}\,C/m^2$

$$E = \frac{\sigma}{\varepsilon_0}$$
$$1 \times 10^5\,V/m = \frac{\sigma}{8.85 \times 10^{-12}}$$
$$\sigma = 1 \times 10^5 + 8.85 \times 10^{-12}$$
$$= 8.85 \times 10^{-7}\,C/m^2$$

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ASSERTION AND REASON

50. **Assertion :** If the distance between parallel plates of a capacitor is halved and dielectric constant is three times, then the capacitance becomes 6 times.

Reason : Capacity of the capacitor does not depend upon the nature of the material.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **SQP 2012**

Capacity of capacitor is directly proportional to dielectric constant and inversely proportional to distance. So, the net effect of making distance halved and making dielectric constant three times will be capacity becoming six times.

As nature of the material (dielectric constant) is a factor influencing the capacity, therefore, Reason is incorrect.

Thus (c) is correct option.

51. **Assertion :** If three capacitors of capacitances $C_1 < C_2 < C_3$ are connected in parallel then their equivalent capacitance $C_P > C_S$.

Reason : $\frac{1}{C_P} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **Main 2004, 2002**

If three capacitors are joined in parallel then their equivalent capacitor will be less than the least value of capacitor so

$$C_P > C_S$$

$$\frac{1}{C_P} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \text{ is incorrect.}$$

Thus (c) is correct option.

52. **Assertion :** A parallel plate capacitor is connected across battery through a key. A dielectric slab of dielectric constant K is introduced between the plates. The energy which is stored becomes K times.

Reason : The surface density of charge on the plate remains constant or unchanged.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **SQP 2004**

In the given cases, $V = V_0$ (remains constant).

Energy stored in the capacitor $U = \frac{1}{2}CV^2$

When a dielectric slab of dielectric constant K is introduced between the plates of the condenser, then

$$C' \longrightarrow KC$$

So energy stored will become K times.

Since $Q = CV$,

So Q will become K times

Hence Surface charge density

$$\sigma' = \frac{KQ}{A} = K\sigma_0$$

Thus (c) is correct option.

53. **Assertion :** The total charge stored in a capacitor is zero.

Reason : The field just outside the capacitor is $\frac{\sigma}{\varepsilon_0}$. ($\sigma$ is the charge density).

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **Main 2014**

Charge stored on the two plates are $+Q$ and $-Q \Rightarrow Q + (-Q) = 0$ and hence Assertion is correct. The field however, outside the plates is zero.

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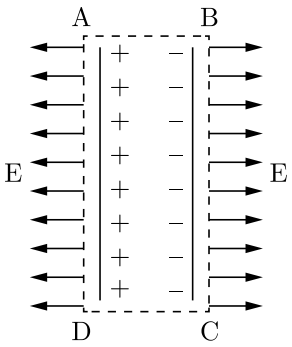


Draw a Gaussian surface $ABCD$ as shown. The field $\vec{E}$ is uniform on faces AD and BC

$$\oint \vec{E} \cdot ds = 0 \text{ yields } \vec{E} = 0$$

Thus (c) is correct option.

54. **Assertion :** Two equipotential surfaces cannot cut each other.

Reason : Two equipotential surfaces are parallel to each other.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **SQP 2010**

Two equipotential surfaces are not necessarily parallel to each other. Thus (c) is correct option.

55. **Assertion :** Electric potential and electric potential energy are different quantities.

Reason : For a system of positive test charge and point charge electric potential energy is equal to electric potential.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

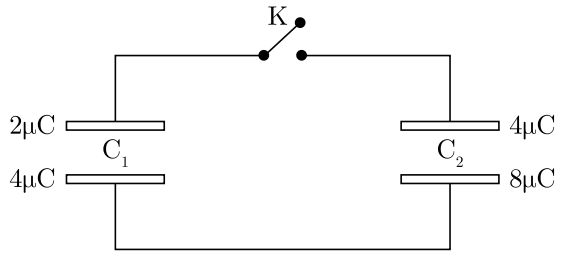
(d) Assertion is incorrect but Reason is correct.

Ans : **Main 2010**

Potential and potential energy are different quantities and cannot be equated.

Thus (c) is correct option.

56. **Assertion :** Charges are given to plates of two plane parallel plate capacitors C_1 and C_2 (such that $C_2 = 2C_1$) as shown in figure. Then the key K is pressed to complete the circuit. Finally the net charge on upper plate and net charge the circuit. Finally the net charge on upper plate and net charge on lower plate of capacitor C_1 is positive.



Reason : In a parallel plate capacitor both plates always carry equal and opposite charge.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **Main 2017**

Charge distribution on each surfaces makes both capacitor of same potential difference hence charge will not flow.

Thus (d) is correct option.

ONE MARK QUESTIONS

57. In an electric dipole, at which point is the electric potential zero?

Ans : **Main 2016**

Electric potential at any point on the equatorial plane of dipole is zero.

58. In which situation is there a displacement current but no conduction current ?

Ans : **SQP 2016**

During charging or discharging there is a displacement current but no conduction current between plates of capacitor.

59. Give two factors which affect capacitance of a conductor.

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Ans : **Main 2012**

1. Material of conductor.
2. Cross-section area of conductor.

60. How much work is done in moving a 500 μC charge between two points on an equipotential surface?

Ans : **SQP 2011, 2009**

For equipotential surface each point is at the same potential, so

$$V_{\text{final}} = V_{\text{initial}}$$

So, $$W = q(V_{\text{final}} - V_{\text{initial}}) = 0$$

61. In a certain $0.5\,\text{cm}^3$ of space, electric potential is found to be 7 V throughout. What is the electric field in this region ?

Ans : **Main 2011**

Zero, because electric potential is same throughout as

$$E = -\frac{dV}{dr}$$

62. How much work is done in taking an electron around a nucleus in a circular path?

Ans : **Main 2025**

The circular path around the nucleus will act as equipotential surface. Hence, work done in moving the electron around the nucleus

$$= e|\Delta V| = e(0) = 0$$

63. Distinguish between a dielectric and a conductor.

Ans : **Comp 2019**

Dielectrics are non-conductors and do not have free electrons at all. While conductor has free electrons in its any volume which makes it able to pass the electricity through it.

64. What is meant by an equipotential surface?

Ans : **Main 2023, 2019**

A surface which have same electrostatic potential at every point on it is known as equipotential surface. A perpendicular drawn on electric field lines gives the equipotential point.

65. What is the amount of work done in moving a point charge Q around a circular arc of radius r at the centre of which another point charge q is located?

Ans : **Main 2014**

work done $W = qV$. Since potential difference between any two point on circumference of circle is zero, so work done will be zero.

66. A hollow metal sphere of radius 5 cm is charged such that potential on its surface is 10 V. What is the potential at the centre of the sphere ?

Ans : **Comp 2021**

The electric potential at every point inside the charged spherical shell is same and equal to the electric potential on its surface. The electric potential at the centre of sphere is 10 V.

67. Can two equipotential surfaces intersect each other ? Justify your answer.

Ans : **Main 2021**

No, two equipotential surfaces cannot intersect each other because :

(i) Two normals can be drawn at intersecting point on two surfaces which gives two directions of E at the same point which is impossible.

(ii) Also two values of potential at the same point is not possible.

68. For any charge configuration, equipotential surface through a point is a normal to the electric field. Justify.

Ans : **Main 2024**

No work is done in moving the test charge from one point of an equipotential surface to the other.

$$W_B - W_A = 0 - \int E \cdot dl$$

$$E \cdot dl = 0$$

Hence, $$E \perp dl$$

69. Why there is no work done in moving a charge from one point to another on an equipotential surface ?

Ans : **Main 2015**

On an equipotential surface, the potential remains constant and thus potential difference (ΔV) is zero.

The work done on a charge q is given as

$$W = q\Delta V$$

Now, as $$\Delta V = 0$$

So, the work done in moving a charge from one point to another on an equipotential surface is zero.

70. Why is there no work done in moving a charge from one point to another on an equipotential surface?

Ans : **SQP 2018**

The potential difference between any two points of equipotential surface is zero. We have,

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$$V_1 - V_2 = \frac{W}{q} = 0$$

$$W = 0$$

Therefore, the work done in moving a charge on an equipotential surface is zero.

71. What is the function of second plate in s parallel plate capacitor?

Ans : **Comp 2024, 2008**

A parallel plate capacitor of two large plane parallel conducting metal plates separated by a small distance. The second plate acts as a neighbouring conductor due to which the potential of first plate is reduced, keeping it same size, due to which the capacitance increase.

72. Why is the dielectric constant of conductors taken as ∞?

Ans : **Main 2013**

When the conductors are placed in the external field, then the induced electric field is equal and opposite to the external field E_0.

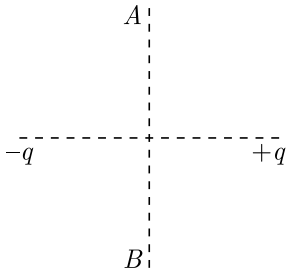
Hence, Net field,

$$E_{\text{Net}} = E_0 - E_m = E_0 - E_0 = 0$$

Since, Dielectric constant,

$$K = \frac{E_0}{E_{\text{net}}} = \frac{E_0}{0} = \infty$$

73. A charge q is moved from a point A above a dipole of dipole moment p to a point B below the dipole in equatorial plane without acceleration. Find the work done in the process.



Ans : **SQP 2017**

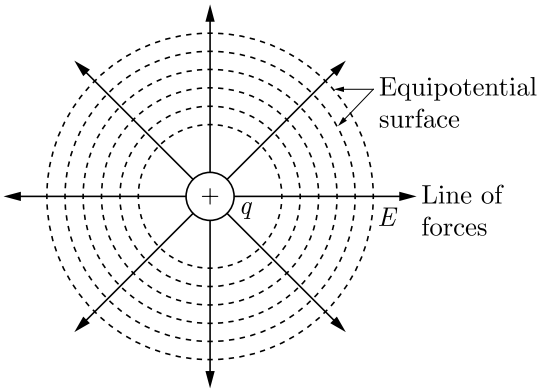
Work done in the process is zero. Because, equatorial plane of a dipole is equipotential surface and work done in moving charge on equipotential surface is zero.

$$W = qW_{AB} = q \times 0 = 0$$

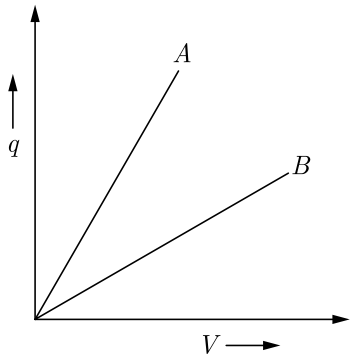
74. Draw equipotential surfaces due to a single point charge.

Ans : **SQP 2020**

Equipotential surfaces due to a single point charge are concentric sphere having charge at the centre.



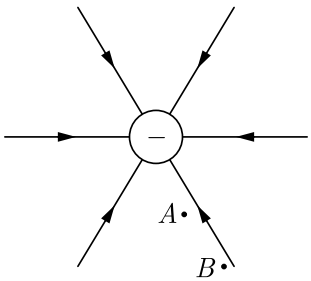
75. The given graph shows the variation of charge q versus potential difference V for two capacitors C_1 and C_2. Both the capacitors have same plate separation but plate area of C_2 is greater than that C_1. Which line (A or B) corresponds to C_1 and why ?



Ans : **Main 2019**

Line B corresponds to C_1 because slope (q/v) of B is less than slope of A.

76. Figure shows the field lines due to a negative point charge. Give the sign of the potential energy difference of a small negative charge between the points A and B.



NODIA

Ans : SQP 2013

$$U = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{r}$$

$$U \propto \frac{1}{r}$$

Hence, $U_A > U_B$

Therefore, $U_A - U_B$ is positive.

TWO MARKS QUESTIONS

77. What are the characteristics of electric potential?

Ans : SQP 2018, 2015

Characteristics of electric potential are as follows:

1. Potential is a scalar quantity.
2. Its value at infinity is zero.
3. It depends only on the distance from the source charge.
4. Potential is positive if $q > 0$ and negative if $q < 0$.

78. Why are equipotential surfaces perpendicular to field lines?

Ans : Main 2017

Electric field should not have any component along the equipotential surface otherwise it will cause the charges on the surface of the conductor to move, i.e. work is done. But no work is done in moving a charge on an equipotential surface. Hence, the equipotential surface is perpendicular to field lines.

79. Define capacitance of a capacitor.

Ans : Main 2020

The capacitance of capacitor may be defined as the charge required to be supplied to either of the conductors of the capacitor so as to increase the potential difference between them by unit amount.

Capacitance,

$$C = \frac{\text{Charge on either plate (Q)}}{\text{Potential difference between the two plates } (V)}$$

SI unit of capacitance is farad (F).

80. Why water has very high dielectric constant?

Ans : SQP 2009

Due to unsymmetrical placement of the atoms of water molecule, it possess permanent electric dipole moment which is about 0.6×10^{-20} Cm. This magnitude of dipole moment is about 10 times more than the induced dipole moment acquired by the molecule. Hence due to this large value of permanent dipole moment, the dielectric constant of water molecules is very high.

81. Write the working principle of a parallel plate capacitor. On what factors, the capacitance of a parallel plate capacitor depends?

Ans : SQP 2008, 2005

When an uncharged, earthed conductor is brought near to a charged conductor, then the potential of later decreases and its charge holding capacity increases.

The capacitance depends on :

1. Geometrical configuration (shape, size and separation) of the system of two conductors.
2. Nature of the dielectric separating two conductors.

82. Define Dielectric strength and Relative permittivity.

Ans : Main 2025, 2021

Dielectric Strength : The maximum electric field that a dielectric can with stand without breakdown (for its insulating property) is called its dielectric strength.

Relative Permittivity : The ratio of the strength of the applied electric field to the strength of the reduced value of the electric field on placing the dielectric between the two plates is called relative permittivity.

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$$

83. Why do electric lines of force never intersect each other? Can two equipotential surfaces intersects?

Ans : SQP 2021

Two electric field lines can never intersect each other because if they intersect, then two tangents drawn at that point will represent two directions of field at that point which is not possible. Two equipotential surface cannot intersect ea-the conductor remains same.

84. Why is the potential inside a hollow spherical charged conductor constant and has the same value as on its surface?

Ans : SQP 2015

Electric field intensity is zero inside the hollow spherical charged conductor. So, no work is done in moving a test charge inside the conductor and on its surface. Therefore, there is no potential

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difference between any two points inside or on the surface of the conductor.

$$V_A - V_B = -\int \vec{E} \cdot \vec{dl} = 0$$
$$V_A = V_B = \text{constant}$$

85. Give the dimensional formula and unit of electric potential.

Ans : **Main 2016**

Dimensional formula of electric potential

Since, $V = \frac{W}{q_0}$

$$= \frac{[ML^2T^{-2}]}{[AT]}$$
$$= [M^1L^2T^{-3}A^{-1}]$$

Units of V

If $W = 1\,J$, $q_0 = 1\,C$, then $V = 1$ volt. So potential at a point in an electric field is said to be 1 V if 1 J work is done in bringing 1 C charge from infinity to that point.

And $1\,V = 1\,JC^{-1}$

86. How can a positively charged body be at zero or negative potential?

Ans : **SQP 2025**

If a positively charged body B is moved gradually towards a small positively charged body A, at a particular distance, the negative charge induced on A due to B will become equal to positive charge initially present on body A. Hence the body A will be at zero potential. If body B is further moved towards A, a negative charge will be induced on body A. Hence body A will be positive charged but at negative potential. So a positively charged body can be at zero or negative potential.

87. What is the importance of equipotential surfaces?

Ans : **SQP 2010**

The drawings of equipotential surface give us a visual picture of both the magnitude as well as direction of electric field intensity in region of space.

In the region of strong electric fields, equipotential surfaces are close together. The reverse is also true. This follows from,

$$E = -\frac{dV}{dr}$$

i.e. $dr = -\frac{dV}{E}$

or $dr \propto \frac{1}{E}$

88. Show that the potential is constant within and at the surface of a charged conductor.

Ans : **Main 2016, 2011**

Since the electric field is equal to negative of potential gradient,

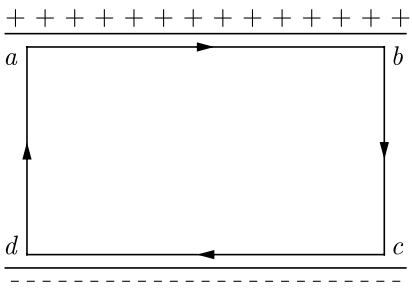
i.e. $E = -\frac{dV}{dx}$

Inside the conductor, $E = 0$

or $V = \text{constant}$

Hence the potential within and at the surface of a charged conductor is constant i.e. surface of a conductor is an equipotential surface.

89. The electric field inside a parallel plate capacitor is E. Find the amount of work done in moving a charge q over a closed rectangular loop $abcda$.



Ans : **Main 2004**

Due to conservative nature of electric force, the work done in moving a charge in a close path in a uniform electric field is zero.

90. What is electrostatic shielding ? How is this property used in actual practice ? Is the potential in the cavity of a charged conductor zero ?

Ans : **Main 2016**

Whatever be the charge and field configuration outside, any cavity in a conductor remains shielded from outside electric influence. The field inside a conductor is zero. This is known as electrostatic shielding.

(i) Sensitive instruments are shielded from outside electrical influences by enclosing them in a hollow conductor.

(ii) During lightning it is safest to sit inside a car, rather than near a tree. The metallic body of a car becomes an electrostatic shielding from lightening.
Potential inside the cavity is not zero. Potential is constant.

NODIA

91. Deduce the expression for the energy stored in a charged capacitor.

Ans : **Main 2005**

We know that,

$$q = CV$$

$$V = q/C$$

$$dW = Vdq = \frac{q}{C}dq$$

Where, q = instantaneous charge,

C = instantaneous capacitance and

V = instantaneous voltage

Total work done in storing charge from 0 to q is given by

$$W = \int_0^q \frac{q}{C}dq = \frac{q^2}{2C}$$

92. Discuss the cause of increase in capacitance of a parallel plate capacitor when

1. A conducting slab is introduced
2. A dielectric slab is introduced.

Ans : **Main 2024**

1. In a conducting slab, large scale movement of free charges reduces the field in the interior of the conductor slab to zero. This decreases the potential difference between the plates resulting in increase in the capacitance.
2. In a dielectric slab, the applied field polarizes the dielectric on account of small scale alignment of dipoles. The field inside the dielectric decreases, decreasing thereby the potential difference between the plates. Thus the capacitance of the capacitors is increased.

93. Why does the electric field inside a dielectric decrease when it is placed in an external electric field?

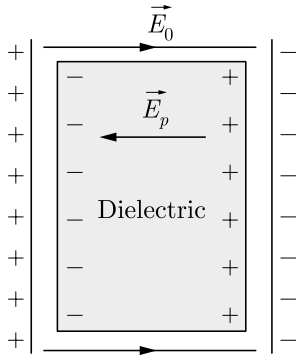
Ans : **Comp 2016**

When a dielectric is placed inside an electric field $\vec{E}_0$, it gets polarised as shown in the figure and electric field $\vec{E}_p$ due to polarisation is produced inside the dielectric in a direction opposite to the electric field $\vec{E}_0$.

Hence, resultant electric field between the plates is,

$$\vec{E} = \vec{E}_0 - \vec{E}_p$$

Hence, $\vec{E} < \vec{E}_0$



94. Two point charges q_1 and q_2 are located at r_1 and r_2, respectively in an external electric field E. Obtain the expression for the total work done in assembling this configuration.

Ans : **SQP 2018**

Work done in bringing the charge q_1 from infinity to position r_1

$$W_1 = q_1 V(r_1) \quad ...(1)$$

Work done in bringing charge q_2 to the position r_2

$$W_2 = q_2 V(r_2) + \frac{q_1 q_2}{4\pi\varepsilon_0 r_{12}} \quad ...(2)$$

Hence, total work done in assembling the two charges.

$$W = W_1 + W_2$$

From equations (1) and (2), we get

$$W = q_1 V(r_1) + q_2 V(r_2) + \frac{q_1 q_2}{4\pi\varepsilon_0 r_{12}}$$

95. Define the dielectric constant of a medium. What is its unit ?

Ans : **SQP 2024**

When a dielectric slab is introduced between the plates of charged capacitor or in the region of electric field, an electric field E_P induces inside the dielectric due to induced charge on dielectric in a direction opposite to the direction of applied external electric field. Hence, net electric field inside the dielectric gets reduced to $E_0 - E_P$, where E_0 is external electric field. The ratio of applied external electric field and reduced electric field is known as dielectric constant K of dielectric medium, i.e.,

$$K = \frac{E_0}{E_0 - E_P}$$

It is dimensionless quantity.

96. A test charge q is moved without acceleration from A to C along the path from A to B and then from B to C in electric field E as shown in the figure.

(i) Calculate the potential difference between A to C.

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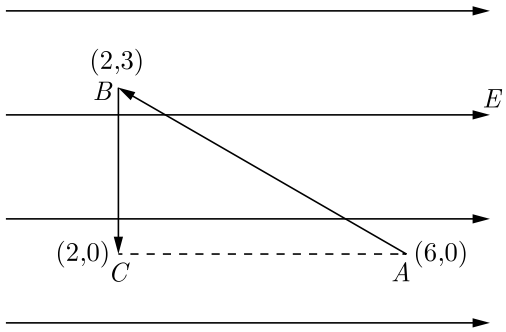
(ii) At which point (of the two) is the electric potential more and why ?



Ans : **Main 2017**

(i) $dV = -E\,dr = -E(6-2) = -4E$

(ii) Electric potential is more at point C as $dV = -E\,dr$, i.e., the electric potential decreases in the direction of the electric field.

97. Show that the capacitance of spherical capacitor is more than that of a spherical conductor.

Ans : **Main 2019, 2017**

The capacitance of a spherical conductor of radius a is given by,

$$C = 4\pi\varepsilon_0 a \qquad ...(1)$$

The capacitance of a spherical capacitor of inner radius a and outer radius b is given by,

$$C' = 4\pi\varepsilon_0\left(\frac{ab}{b-a}\right) \qquad ...(2)$$

Dividing equation (2) by (1), we get

$$\frac{C'}{C} = 4\pi\varepsilon_0\left(\frac{ab}{b-a}\right) \times \frac{1}{4\pi\varepsilon_0 a}$$

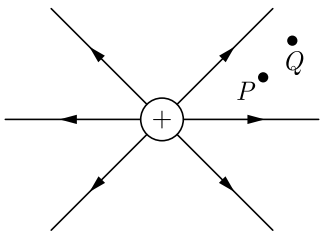
$$= \frac{b}{b-a}$$

Since, $\frac{b}{b-c} > 1$

Hence, $\frac{C'}{C} > 1$

or $C' > C$

98. The figure shows the field lines of a positive charge. Is the work done by the field in moving a small positive charge from Q to P positive or negative?



Ans : **Comp 2020**

Work done by charge is given by,

$$W = q \text{ (potential at } Q - \text{ potential at } P)$$

where, q = small positive charge

The electric potential at a point distant r due to the field created by a positive charge Q is given by,

$$V = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r}$$

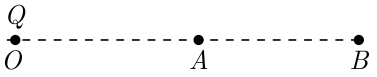
Since, $r_p < r_Q$

$V_p > V_Q$

So, work done will be negative.

99. A point charge Q is placed at point O as shown in the figure. Is the potential difference $(V_A - V_B)$ positive, negative or zero if Q is

1. Positive, 2. Negative



Ans : **SQP 2020**

Let the distance of points A and B from charge Q be r_A and r_B respectively.

Hence, Potential difference between points A and B,

$$V_A - V_B = \frac{Q}{4\pi\varepsilon_0}\left[\frac{1}{r_A} - \frac{1}{r_B}\right]$$

As $r_A = OA,\ r_B = OB$

and $r_A < r_B,\ \frac{1}{r_A} > \frac{1}{r_B}$

Therefore, $\left[\frac{1}{r_A} - \frac{1}{r_B}\right]$ has positive value.

$(V_A - V_B)$ depends on the nature of charge Q,

1. $(V_A - V_B)$ is positive when $Q > 0$.
2. $(V_A - V_B)$ is negative when $Q < 0$.

THREE MARKS QUESTIONS

100. Can we create an electric field in which all the lines of force are parallel but their density increases continuously in a direction perpendicular to the lines of force?

Ans : **Main 2015**

We cannot create such an electric field. Electric field is a conservative field, i.e. work done along a closed path in the field will be zero. In the field, that we are assuming, work done will not be equal to zero.

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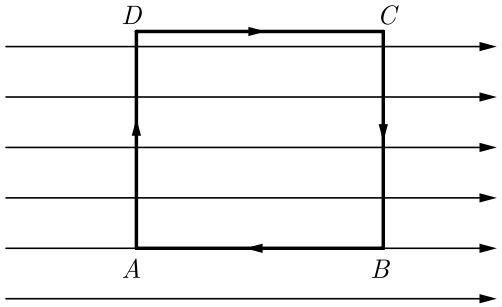
Work done along the paths CB and AD is zero. Work done along the path BA is more than that of along the path DC. Hence, net work done along the whole closed path is not zero.



101. An infinitely large thin plane sheet has a uniform surface charge density $+\sigma$. Obtain the expression for the amount of work done in bringing a point charge q, from infinity to a point distant r, in front of the charged plane sheet.

Ans : **Main 2017, 2015**

Let P be a point at distance r from the sheet.

The required work done to bring point charge q from infinity to P is

$$W = q \cdot (V_P - V_\infty) \qquad ...(1)$$

Now, $V_P - V_\infty = -\int_\infty^r \vec{E} \cdot \vec{dr}$

$$= -\int_\infty^r E \cdot dr = -\int_\infty^r \left(\frac{\sigma}{2\varepsilon_0}\right) \cdot dr$$

$$\frac{-\sigma}{2\varepsilon_0}\int_\infty^r dr = -\frac{\sigma}{2\varepsilon_0} \cdot [r]_\infty^r$$

[Since, field in front of an infinity large plane sheet of charge is uniform and is given by $\frac{\sigma}{2\varepsilon_0}$.]

$$-\frac{\sigma}{2\varepsilon_0}(r - \infty) = \infty$$

$$V_P - V_\infty = \infty$$

From equations (1), $W = \infty$

102. Define conductors and insulators. Why conductors were called non-electrics and insulators were called dielectrics?

Ans : **Main 2017**

Conductors and Insulators : A substance, which allows an electric current to flow through itself, is called a conductor. It has free electrons inside itself. Examples are metals, human body, earth etc.

A substance, which does not allow an electric current to flow through itself, is called an insulator. It does not have free electrons inside itself. Examples are ebonite, glass, quartz, rubber, plastic etc.

Non-electric and Dielectric : When a conductor was rubbed, electric charge produced on it was conducted away through body to earth. As no charge was found present of the rubbed conductor, it was supposed to have no charge. Hence it was called non-electric.

On the other hand, charge stays in an insulator when it is rubbed. It was supposed to have charge. Hence is was called dielectric.

103. 1. Draw equipotential surfaces due to a point $Q > 0$.

2. Are these surfaces equidistant from each other? If not, explain why.

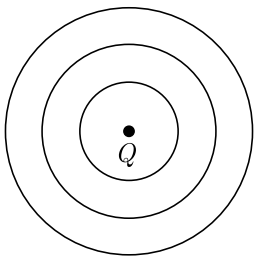
Ans : **Main 2025**

The equipotential surfaces due to a charge Q are as shown below :

1. The equipotential surfaces are spherical concentric spheres.
2. The equipotential surfaces are not equidistant.

Since, $E = -\frac{dV}{dr}$

$$dr = -\frac{dV}{E}$$



Clearly, as E decreases, the distance between the equipotential surfaces goes on increasing as shown in the above figure.

104. A charge Q is given to three capacitors C_1, C_2 and C_3 connected in parallel. Determine the charge on each.

Ans : **SQP 2013**

In parallel combination of capacitors, the total charge,

$$Q = Q_1 + Q_2 + Q_3$$

As potential difference across each capacitor is same, therefore

Since, $C_{eq} = C_1 + C_2 + C_3$

Hence, $\text{P.D.} = V = \frac{Q}{C_1 + C_2 + C_3}$

$$= \frac{Q_1}{C_1} = \frac{Q_2}{C_2} = \frac{Q_3}{C_3}$$

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Charge on C_1, $Q_1 = \dfrac{C_1}{C_1+C_2+C_3}Q$

Charge on C_2, $Q_2 = \dfrac{C_2}{C_1+C_2+C_3}Q$

Charge on C_3, $Q_3 = \dfrac{C_3}{C_1+C_2+C_3}Q$

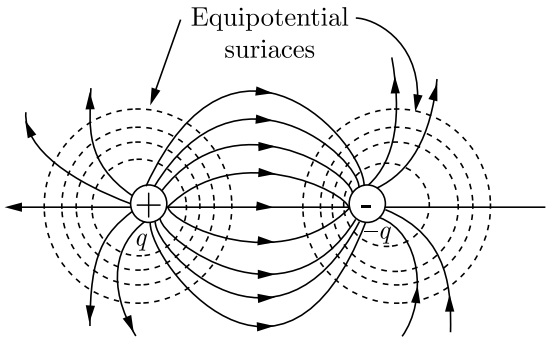
105. Two point charges $3\,\mu C$ and $-3\,\mu C$ are placed at points A and B, 5 cm apart.

(i) Draw the equipotential surfaces of the system.

(ii) Why do equipotential surfaces get close to each other near the point charge ?

Ans : **SQP 2024, 2009**

(i) Equipotential surfaces



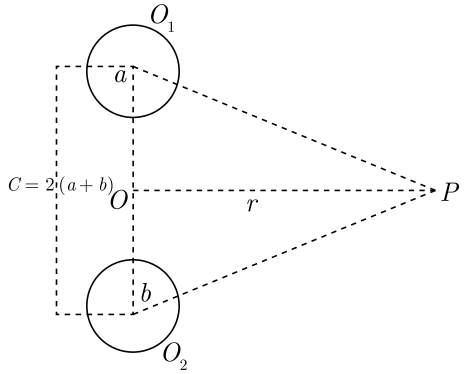
(ii) Equipotential surfaces get closer to each other near the point charges as strong electric field is produced there.

$$E = -\frac{\Delta V}{\Delta r}$$

and $$E \propto -\frac{1}{\Delta r}$$

For a given equipotential surface, small Δr represents strong electric field and vice-versa.

106. Find the P.E. associated with a charge q if it were present at the point P with respect to the 'set up' of two charged spheres, arranged as shown. Here O is the mid-point of the line O_1O_2.



Ans : **SQP 2013**

$$r_1 = O_1P = \sqrt{r^2+(2a+b)^2}$$

$$r_2 = O_2P = \sqrt{r^2+(a+2b)^2}$$

$$V = \frac{1}{4\pi\varepsilon_0}\left[\frac{Q_1}{r_1}+\frac{Q_2}{r_2}\right]$$

P.E. of charge, q at $P = qV$

$$= \frac{q}{4\pi\varepsilon_0}\left[\frac{Q_1}{[r^2+(2a+b)^2]^{1/2}}+\frac{Q_2}{[r^2+(a+2b)^2]^{1/2}}\right]$$

107. Two charged spherical conductors of radii R_1 and R_2 when connected by a conducting plate respectively. Find the ratio of their surface charge densities in terms of their radii.

Ans : **Main 2004**

Surface charge density is given by

$$\sigma = \frac{q}{4\pi R^2}$$

After connecting both the conductors, their potentials will become equal.

$$V_1 = V_2$$

$$\frac{Kq_1}{R_1} = \frac{Kq_2}{R_2}$$

[Since for spherical conductors]

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{R}$$

$$V = \frac{Kq}{R}$$

$$\frac{q_1}{q_2} = \frac{R_1}{R_2}$$

$$\frac{\sigma_1}{\sigma_2} = \frac{q_1/4\pi R_1^2}{q_2/4\pi R_2^2}$$

$$= \frac{q_1}{q_2}\left(\frac{R_2}{R_1}\right)^2 = \frac{R_2}{R_1}$$

108. The equipotential surfaces of a uniform electric field E. Obtain an expression for equivalent capacitance C when three capacitors having capacitance C_1, C_2 and C_3 are connected in series.

Ans : **Main 2016, 2012**

In series combination, charge on each capacitor will be same. The potential will be divided across the individual capacitors.

Let a battery of emf V is connected with the series combination of capacitors and let V_1, V_2 and V_3 are potential difference across each capacitor, then

$$V_1 = \frac{Q}{C_1},\ V_2 = \frac{Q}{C_2} \text{ and } V_3 = \frac{Q}{C_3}$$

But $$V = V_1 + V_2 + V_3$$

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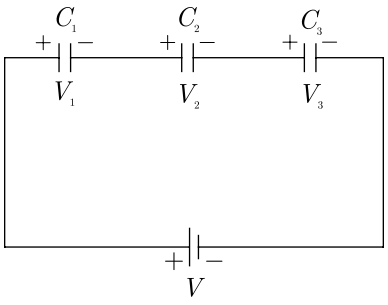


$$V = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}$$

$$V = Q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$$

But $V = \dfrac{Q}{C_{eq}}$

where, C_{eq} is equivalent capacitance of the combination.

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

109. A parallel plate capacitor is charged by a battery, which is then disconnected. A dielectric slab having dielectric constant (relative permittivity) K, is now introduced between its two plates in order to occupy the space completely.

State, in terms of K, its effect on the following

(i) the capacitance of the capacitor.

(ii) the potential difference between its plates.

(iii) the energy stored in the capacitor.

Ans : **Main 2025**

(i) Let the initial capacitance,

$$C_0 = \varepsilon_0 \frac{A}{d}$$

So, the final capacitance, after the insertion of dielectric medium

$$C = K\varepsilon_0 = \frac{A}{d} = KC_0$$

(ii) Initial potential difference,

$$V_0 = \frac{Q_0}{C_0}$$

New potential difference,

$$V = \frac{Q_0}{C} = \frac{Q_0}{KC_0} = \frac{V_0}{K}$$

(iii) Also, initial energy stored in capacitor,

$$E_0 = \frac{Q_0^2}{2C_0}$$

New energy stored,

$$E = \frac{Q_0^2}{2C}$$

$$= \frac{Q_0^2}{2(KC_0)} = \frac{E_0}{K}$$

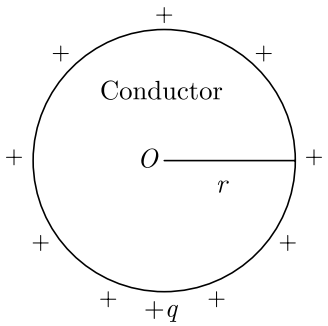
110. Show that the capacitance of an insulated spherical conductor is directly proportional to the radius of the spherical conductor.

Ans : **Main 2014**

Consider an isolated spherical conductor of radius r having charge $+q$, which reside at its surface only. The charge behaves as if it is concentrated at its centre O. If V is the potential at the surface of the spherical conductor, then

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r} \qquad ...(1)$$

Hence, capacitance of the spherical conductor is given by,



$$C = \frac{q}{V} = \frac{q \cdot 4\pi\varepsilon_0 r}{q}$$

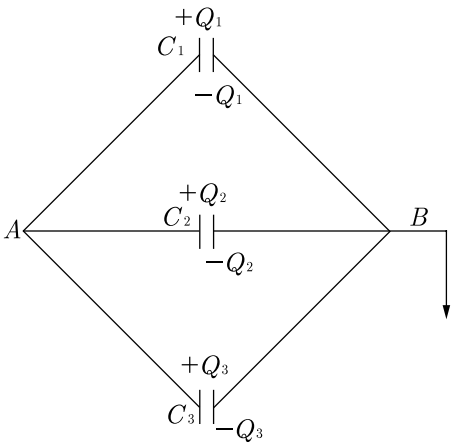
$$= 4\pi\varepsilon_0 r$$

or $C \propto r$

111. Deduce an expression for equivalent capacitance C when three capacitors C_1, C_2 and C_3 are connected in parallel.

Ans : **Main 2024**

Suppose $+Q$ charge is given to the point A by means of an electric source. This charge is distributed on all the three capacitors according to their capacitances.



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If the charges on the capacitors C_1, C_2 and C_3 be Q_1, Q_2 and Q_3 respectively, then

$$Q_1 = C_1 V,\ Q_2 = C_2 V \text{ and } Q_3 = C_3 V$$

The total charge on all the three capacitors is

$$\begin{aligned} Q &= Q_1 + Q_2 + Q_3 \\ &= C_1 V + C_2 V + C_3 V \\ &= V(C_1 + C_2 + C_3) \qquad ...(1) \end{aligned}$$

If the capacitor of this combination be C, then

$$Q = CV \qquad ...(2)$$

Combining Eqs. (1) and (2), we obtain

$$\begin{aligned} CV &= V(C_1 + C_2 + C_3) \\ C &= C_1 + C_2 + C_3 \end{aligned}$$

The equivalent capacitance of the capacitors connected in parallel is equal to the sum of their individual capacitance.

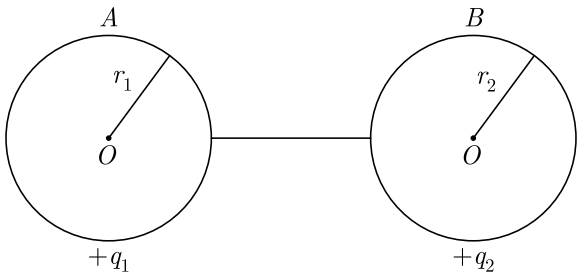
112. Two copper spheres of radii r_1 and r_2 having charges q_1 and q_2 are connected by means of a wire. What is the electric conditions that no charge flows between them?

Ans : **SQP 2019**

In figure (as shown below), we have two copper spheres A and B of radii r_1 and r_2 having charges q_1 and q_2 respectively.

Potential of A, $\quad V_1 = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1}{r_1}$

Potential of B, $\quad V_2 = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q_2}{r_2}$



On connecting these two spheres by a wire, the charge will flow from a body at higher potential to the body at low potential, till the potential of both spheres becomes equal.

So the electrical condition that no charge flows between them is that when,

Potential of sphere A = Potential of sphere B

$$\frac{1}{4\pi\varepsilon_0}\frac{q_1}{r_1} = \frac{1}{4\pi\varepsilon_0}\frac{q_2}{r_2}$$

$$q_1 r_2 = q_2 r_1$$

This is the condition when flow of charge will stop.

113. How does electric potential vary from point to point due to a thin charged spherical shell? Draw a graph showing variation of potential with distance.

Ans : **SQP 2008, 2004**

For a uniformly charged spherical shell, the electric field outside the shell is as if the entire charge is concentrated at the shell is given by

$$V = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{r} \qquad (r \geq R)$$

where q is the total charge on the shell and R is its radius.

As the electric field inside the shell is zero.

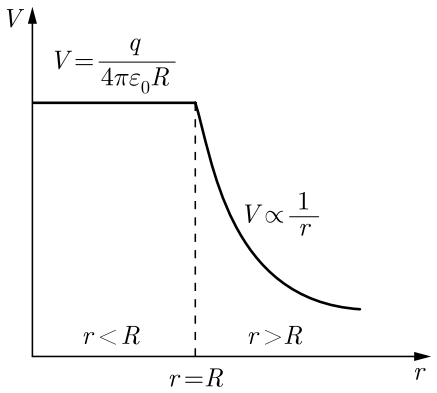
Hence, $\quad E = -\dfrac{dV}{dr}$

$$= 0$$

$$V = \text{constant}$$

Therefore, the potential inside the shell is constant (as no work is done in moving a charge inside the shell), and hence, it equals to its value at the surface, which is

$$V = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{R}$$



A graph showing the variation of potential with distance is given above.

114. What is polarization of charge? Which the help of a diagram show why the electric field between the plates of capacitor reduces on introducing a dielectric slab. Define the dielectric constant on the basis of these fields.

Ans : **Main 2011, 2009**

The induced dipole moment developed per unit volume in a dielectric slab on placing it inside the electric field is called polarisation.

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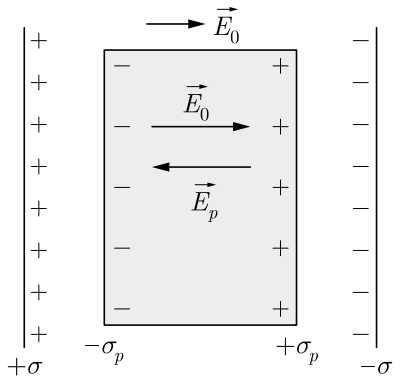


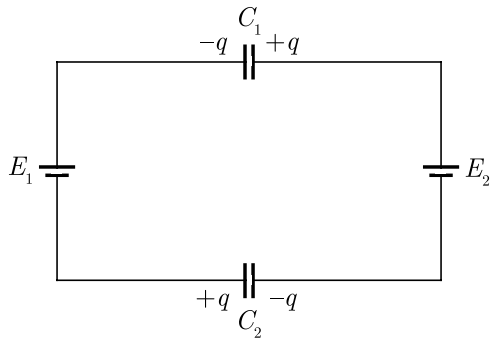
Let $\vec{E}_0$ be the uniform external electric field. When a dielectric slab is placed in uniform electric field, then the molecules get polarised, due to which $-\sigma_p$ (charge density due to polarisation) will appear near the positive plate and $+\sigma_p$ will appear in the dielectric near the negative plate.

Therefore, due to polarization of molecules, electric field will appear will appear in the opposite direction, and the net electric field inside the dielectric will be

$$\vec{E} = \vec{E}_0 - \vec{E}_p < \vec{E}_0$$

So, the dielectric constant is defined as the ratio of the electric field in vacuum to the electric field in medium.

115. Determine the potential difference across the plates of the capacitor C_1 of the network shown in the figure. [Assume $E_2 > E_1$].



Ans : Main 2012

Let $E_2 > E_1$

Therefore, right plate of C_1 has charge $+q$ and left plate of C_1 has charge $-q$. On the same basis, left plate of C_2 has charge $+q$ and right plate of C_2 has charge $-q$.

In closed circuit, potential difference $dV = 0$

$$\frac{q}{C_1} + E_1 + \frac{q}{C_2} - E_2 = 0$$

or
$$q\left(\frac{1}{C_1} + \frac{1}{C_2}\right) = E_2 - E_1$$

$$q\left(\frac{C_2 + C_1}{C_1 C_2}\right) = E_2 - E_1$$

$$q = \frac{(E_2 - E_1)\, C_1 C_2}{C_1 + C_2}$$

Hence, potential difference across left and right plates of C_1 is

$$V = \frac{q}{C_1} = \frac{(E_2 - E_1)\, C_2}{C_1 + C_2}$$

116. A slab of material of dielectric constant K has the same area as that of the plates of a parallel plate capacitor but has the thickness $d/2$, where d is the separation between the plates. Find out the expression for its capacitance when the slab is inserted between the plates of the capacitor.

Ans : Comp 2017

Initially when there is vacuum between the two plates, the capacitance of the two-parallel plates is,

$$C_0 = \frac{\varepsilon_0 A}{d}$$

where A is the area of parallel plates.

Suppose that the capacitor is connected to a battery, an electric field E_0 is produced.

Now if we insert the dielectric slab of thickness $t = d/2$, the electric field reduces to E.

Now the gap between plates is divided in two parts, for distance t there is electric field E and for the remaining distance $(d - t)$ the electric field is E_0.

If V be the potential difference between the plates of the capacitor, then

$$V = E_t + E_0(d - t)$$

$$V = \frac{Ed}{2} + \frac{E_0 d}{2}$$

$$= \frac{d}{2}(E + E_0) \qquad \left(\text{since } t = \frac{d}{2}\right)$$

$$V = \frac{d}{2}\left(\frac{E_0}{K} + E_0\right)$$

$$= \frac{dE_0}{2K}(K+1) \qquad \left(\text{As, } \frac{E_0}{E} = K\right)$$

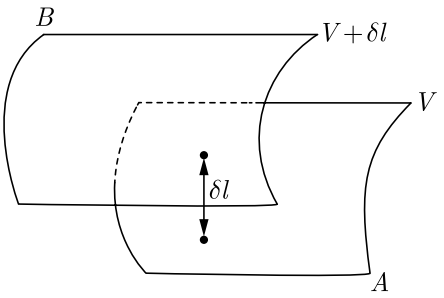
Now, $E_0 = \dfrac{\sigma}{\varepsilon_0} = \dfrac{q}{\varepsilon_0 A}$

$$V = \frac{d}{2K} \cdot \frac{q}{\varepsilon_0 A}(K+1)$$

$$C = \frac{q}{V} = \frac{2K\varepsilon_0 A}{d(K+1)}$$

NODIA

117. Two closely spaced equipotential surfaces A and B with potentials V and $V+\delta V$,(where δV is the change in V) are kept δl distance apart as shown in the figure. Deduce the relation between the electric field and the potential gradient between them. Write the two important conclusions concerning the relation between the electric field and electric potential.



Ans : **Main 2014**

Work done in moving a unit positive charge along distance δl,

$$|E_l|\delta l = V_A - V_B = V - (V+\delta V)$$
$$= -\delta V$$
$$E = \frac{-\delta V}{\delta l}$$

(i) Electric field is in the direction in which the potential decreases steepest.

(ii) Magnitude of electric field is given by the change in the magnitude of potential per unit displacement normal to the equipotential surface at the point.

118. Obtain the expression for the energy stored per unit volume in a charged parallel plate capacitor.

Ans : **SQP 2007**

The energy of a charged capacitor is measured by the total work done in charging the capacitor to a given potential.

Let us assume that initially both the plates are uncharged. Now, we have to repeatedly remove small positive charges from one plate and transfer them to other plate.

Now, when an additional small charge (dq) is transferred from one plate to another, the small work done is given by

$$dW = V' dq = \frac{q'}{C} dq$$

Let charge on plate, when dq charge is transferred is q'.

The total work done in transferring charge Q is given by

$$W = \int_0^Q \frac{q'}{C} dq = \frac{1}{C}\int_0^Q q' dq$$
$$= \frac{1}{C}\left[\frac{(q')^2}{2}\right]_0^Q = \frac{Q^2}{2C}$$

This work is stored as electrostatic potential energy U in the capacitor.

$$U = \frac{Q^2}{2C} = \frac{(CV)^2}{2C} \quad [\text{since } Q = CV]$$
$$U = \frac{1}{2}CV^2$$

The energy stored per unit volume of space in a capacitor is called energy density.

$$u = \frac{\frac{1}{2}CV^2}{A.d} = \frac{1}{2}\frac{\varepsilon_0 A V^2}{d^2 A}$$

Energy density, $u = \frac{1}{2}\varepsilon_0 E^2$

Total energy stored in series combination or parallel combination of capacitors is equal to the sum of energies stored in individual capacitor.

i.e., $U = U_1 + U_2 + U_3 + ...$

119. Derive the expression for the capacitance of a parallel plate capacitor having plate area A and plate separation d.

Ans : **Main 2014, 2013**

Parallel plate capacitor consists of two thin conducting plates each of area A held parallel to each other at a suitable distance d. One of the plates is insulated and other is earthed. There is a vacuum between the plates.

Suppose, the plate X is given a charge of $+q$ coulomb. By induction, $-q$ coulomb of charge is produced on the inner surface of the plate Y and $+q$ coulomb on the outer surface Since, the plate Y is connected to the earth, the $+q$ charge on the outer surface flows to the earth. Thus, the plates X and Y have equal and opposite charges.

Suppose the surface density of charge on each plate is σ. We know that the intensity of electric field at a point between two plane parallel sheets of equal and opposite charges is σ/ε_0, where ε_0 is the permittivity of free space.

The intensity of electric field between the plates will be given by $E = \frac{\sigma}{\varepsilon_0}$.

The charge on each plate is q and the area of each plate is A. Thus,

$$\sigma = \frac{q}{A}$$

and $$E = \frac{q}{\varepsilon_0 A} \quad ...(1)$$

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Now, let the potential difference between the two plates be V volt. Then, the electric field between the plates is given by

$$E = \frac{V}{d}$$

or $$V = Ed$$

Substituting the value of E from Equation (1), we get

$$V = \frac{qd}{\varepsilon_0 A}$$

Capacitance of the capacitor is

$$C = \frac{q}{V} = \frac{q}{qd/\varepsilon_0 A}$$

or $$C = \frac{\varepsilon_0 A}{d}$$

Here, $$\varepsilon_0 = 8.85 \times 10^{-12}\,\mathrm{C}^2/\mathrm{Nm}^2$$

It is clear from this formula that in order to obtain high capacitance

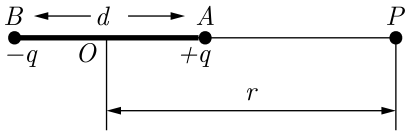
(a) A should be large, i.e., the plates of large area should be taken.

(b) d should be small, i.e., the plates should be kept closer to each other.

120. Obtain an expression for electric potential V at a point in an end-on-position, i.e. axial position of an electric dipole.

Ans : **Main 2019**

Let the electric dipole AB is placed in a medium of dielectric constant K. The electric dipole has charges $+q$ and $-q$ separated by the distance d.



We have to determine the electric potential at point P, situated at distance r from the centre of the electric dipole.

The distance of point P from charge $+q$ is $\left(r - \frac{d}{2}\right)$ from charge $-q$ is $\left(r + \frac{d}{2}\right)$, then potential due to $+q$ charge at point P,

$$V_1 = \frac{1}{4\pi\varepsilon_0 K}\left[\frac{q}{r-(d/2)}\right]$$

Potential due to $-q$ charge at point P,

$$V_2 = \frac{1}{4\pi\varepsilon_0 K}\left[\frac{-q}{r+(d/2)}\right]$$

Resultant potential at point, P, $V = V_1 + V_2$

$$V = \frac{q}{4\pi\varepsilon_0 K}\left[\frac{1}{r-(d/2)} - \frac{1}{r+(d/2)}\right]$$

$$= \frac{1}{4\pi\varepsilon_0 K}\left[\frac{q \times d}{r^2 - (d/2)^2}\right]$$

If the dipole moment is p, then $p = q \times d$

$$V = \frac{1}{4\pi\varepsilon_0 K}\left[\frac{p}{r^2 - (d/2)^2}\right]$$

If $\frac{d}{2} << r$, then neglecting $\left(\frac{d}{2}\right)^2$ in comparison to r^2,

$$V = \frac{1}{4\pi\varepsilon_0 K}\cdot\left(\frac{p}{r^2}\right)$$

If the electric dipole is situated in air or vaccum, then $K = 1$,

$$V = \frac{1}{4\pi\varepsilon_0}\left[\frac{p}{r^2}\right]$$

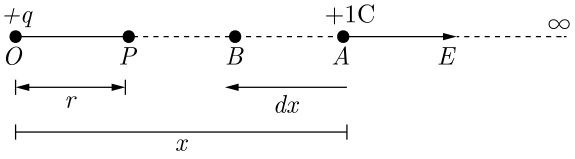
121. Show that electric potential at a point P, at a distance r from a fixed point charge Q is given by

$$V = \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{Q}{r}$$

Ans : **SQP 2018, 2008, Main 2017**

We have to apply the relation between electric field $(\vec{E})$ and potential difference dV as $dV = -\vec{E} \cdot d\vec{r}$

Let P be the point at a distance r from the origin O at which the electric field E due to charge $+q$ is required.



The electric potential at a point P is the amount of work done in carrying a unit positive charge from ∞ to P.

As work done is independent of the path, we choose a convenient path along the radial direction from infinity to the point P without acceleration.

Let A be an intermediate point on this path, where $OA = x$.

The electrostatic force on unit positive charge A is $$F = \frac{1}{4\pi\varepsilon_0}\frac{q}{x^2}, \text{ along } OA$$

Small work done in moving the charge through a distance dx from A to B

$$dW = \vec{F} \cdot d\vec{x} = Fdx\cos 180^\circ = -Fdx \qquad [\cos 180^\circ = -1]$$

$$dW = -Fdx$$

Total work done in moving unit positive charge from ∞ to the point P is

$$W = \int_\infty^r -Fdx = \int_\infty^r -\frac{1}{4\pi\varepsilon_0}\frac{q}{x^2}dx$$

$$= -\frac{q}{4\pi\varepsilon_0}\int_\infty^r x^{-2}dx$$

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$$= -\frac{q}{4\pi\varepsilon_0}\left[\frac{-1}{x}\right]_{\infty}^{r}$$

$$= \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{r} - \frac{1}{\infty}\right] \qquad \left[\int x^{-2}dx = -\frac{1}{x}\right]$$

$$W = \frac{q}{4\pi\varepsilon_0 r}$$

From the definition of electric potential, this work is equal to the potential at point P.

$$V = \frac{q}{4\pi\varepsilon_0 r}$$

122. A parallel plate capacitor is charged by a battery to a potential. The battery is disconnected and a dielectric slab is inserted to completely fill the space between the plates.

How will

(a) its capacitance

(b) electric field between the plates and

(c) energy stored in the capacitor be affected? Justify your answer giving necessary mathematical expression for each case.

Ans : **Comp 2011**

On introduction of dielectric slab in a isolated charged capacitor.

(a) The capacitance (C') becomes Ks times of original capacitor as

$$C = \frac{\varepsilon_0 A}{d}$$

and $$C' = \frac{K\varepsilon_0 A}{d}$$

(b) The total charge on the capacitor remains conserved on introduction of dielectric slab. Also, the capacitance of capacitor increases to K times of original values.

$$CV = C'V'$$

$$CV = (KC)V'$$

$$V' = \frac{V}{K}$$

New electric field,

$$E' = \frac{V'}{d} = \left(\frac{V/K}{d}\right)$$

$$= \left(\frac{V}{d}\right)\frac{1}{K} = \frac{E}{K}$$

On introduction of dielectric medium new electric field E' becomes $\frac{1}{K}$ times of its original value.

(c) Energy stored initially,

$$U = \frac{q^2}{2C}$$

Energy stored later,

$$U' = \frac{q^2}{2(KC)} \qquad [\text{Since, } C' = KC]$$

where, K = dielectric constant of medium

$$U' = \frac{1}{K}\left(\frac{q^2}{2C}\right)$$

$$U' = \frac{1}{K}(U)$$

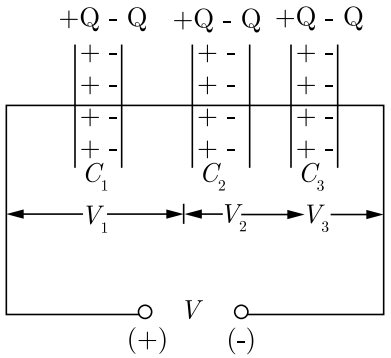
$$U' = \frac{1}{K} \times U$$

The energy stored in the capacitor decreases and becomes $\frac{1}{K}$ times of original energy.

123. Show that the effective capacitances C of a series combination of three capacitors C_1, C_2 and C_3 is given by $C = \frac{C_1 C_2 C_3}{C_1 C_2 + C_2 C_3 + C_3 C_1}$.

Ans : **Main 2009**

In series combination of capacitors, same charge lie on each capacitor for any value of capacitances.



Also, potential difference across the combination is equal to the algebraic sum of potential differences across each capacitor.

i.e., $$V = V_1 + V_2 + V_3$$

where, V_1, V_2, V_3 and V are the potential differences across C_1, C_2, C_3 respectively and equivalent capacitor, respectively.

Hence, $$q = C_1 V_1$$

$$V_1 = \frac{q}{C_1}$$

Similarly, $$V_2 = \frac{q}{C_2}$$

and, $$V_3 = \frac{q}{C_3}$$

Total potential difference,

$$V = \frac{q}{C_1} + \frac{q}{C_2} + \frac{q}{C_3}$$

$$\frac{V}{q} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Since, $$\frac{V}{q} = \frac{1}{C},$$

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where C is equivalent capacitance of combination

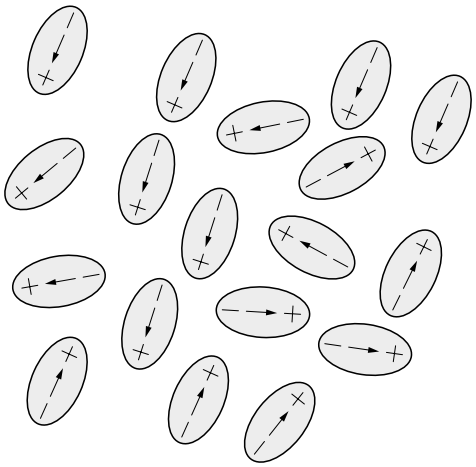
or $$\frac{1}{C} = \frac{C_2 C_3 + C_3 C_1 + C_1 C_2}{C_1 C_2 C_3}$$

$$C = \frac{C_1 C_2 C_3}{C_1 C_2 + C_2 C_3 + C_3 C_1}$$

124. What do you mean by polar molecules? What happens to them when electric field is applied?

Ans : **Main 2012**

A polar molecule is one in which the centre of gravity of the positive charge (i.e. protons) does not coincide with the centre of gravity of the negative charges (i.e. electrons). Due to finite separation between the positive and negative charge, polar molecules are permanent electric dipoles and have permanent electric dipole moments e.g. HCl, NH_3, H_2O, CO_2 are polar molecules. In the absence of electric field, the dipole moment of these polar molecules point in random direction and arrange themselves in closed chains [Figure (a)] and net dipole moment is zero.

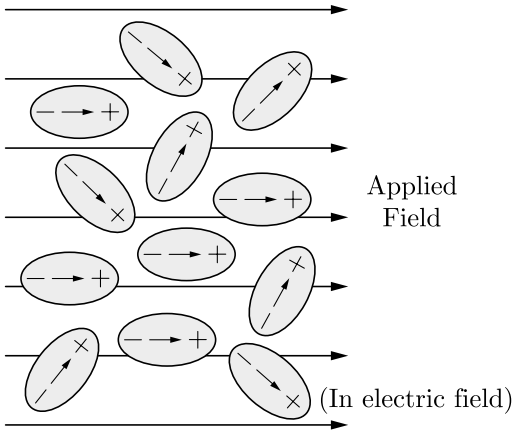


(No electric field)

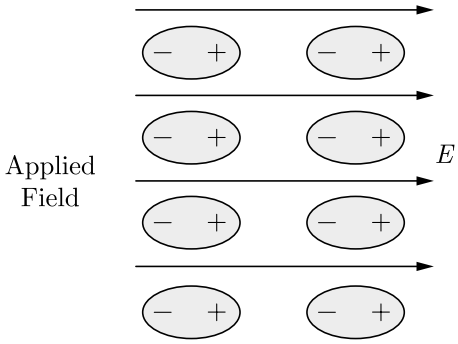
(a)

Effect of Applied Electric Field on Polar Molecules

An applied electric field merely aligns the polar molecules parallel to itself. Because the molecules are in constant thermal agitation, the alignment is not complete as shown in Figure (b). However, the alignment increases as the applied electric field is increased or as the temperature is decreased Figure (c). The dipole moment may also be increased by the applied electric field.



(b)



(c)

FOUR MARKS QUESTIONS

125. Find the ratio of the potential difference that must be applied across the parallel and series combination of two capacitors C_1 and C_2 with their capacitances in the ratio 1 : 2 so that the energy stored in the two cases becomes the same.

Ans : **Main 2019**

As we know that,

$$U_S = \frac{1}{2} C_S V_S^2$$

$$U_P = \frac{1}{2} C_P V_P^2$$

Also, $$\frac{C_1}{C_2} = \frac{1}{2}$$ (given)

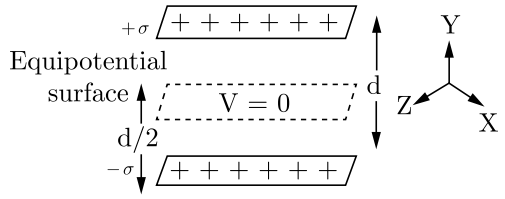
$$C_2 = 2C_1$$

$$\frac{V_{\text{series}}}{V_{\text{parallel}}} = \sqrt{\frac{C_{\text{equivalent parallel}}}{C_{\text{equivalent series}}}}$$
$$= \sqrt{\frac{C_1 + C_2}{\frac{C_1 C_2}{C_1 + C_2}}}$$
$$= \frac{C_1 + C_2}{\sqrt{C_1 C_2}} = \frac{3C_1}{\sqrt{2C_1^2}} = \frac{3}{\sqrt{2}}$$

126. Two uniformly large parallel thin plates having charge densities $+\sigma$ and $-\sigma$ are kept in the X-Z plane at a distance d apart. Sketch and equipotential surface due to electric field between the plates. If a particle of mass m and charge $-q$ remains stationary between the plates, what is the magnitude and direction of this field ?

Ans : **Comp 2013**

The equipotential surface is at a distance $d/2$ from either plate in X-Z plane. For a particle of charge $(-q)$ at rest between the plates, then



(i) weight mg acts vertically downward

(ii) electric force qEs acts vertically upwards.

So, $mg = qE$

$$E = \frac{mg}{q},$$

Vertically downward, i.e. along $(-)$ Y-axis.

127. A capacitor of capacitance C is charged fully by connecting it to a battery of emf E. It is then disconnected from the battery. If the separation between the plates of the capacitor is now doubled, how will the following change ?

(i) charge stored by the capacitor.

(ii) field strength between the plates.

(iii) energy stored by the capacitor.

Ans : **SQP 2016**

(i) Charge remains same, as after disconnecting capacitor no transfer of charge take place.

(ii) Electric field, $E = \frac{\sigma}{\varepsilon_0} = \frac{q}{\varepsilon_0 A}$ remain same, as there is no change in charge.

(iii) Energy stored $= \frac{q^2}{2C} = \frac{q^2}{2\left(\frac{\varepsilon_0 A}{d}\right)} = \frac{q^2 d}{2\varepsilon_0 A}$

Energy will be doubled as separation between the plates (d) is doubled.

128. Draw a plot showing the variation of (i) electric field (E) and (ii) electric potential (V) with distance r due to a point charge Q.

Ans : **SQP 2009**

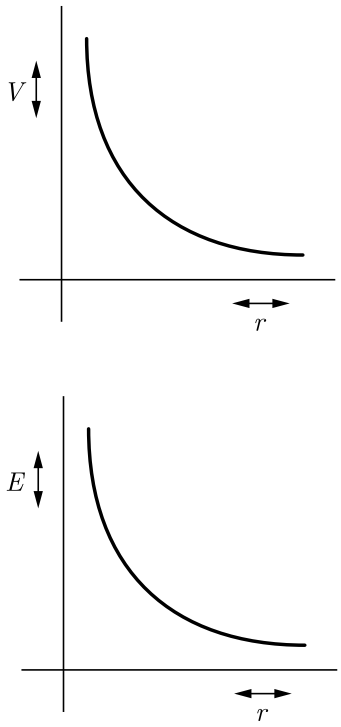
For point charge Q,

Electric potential, $V = \frac{Q}{4\pi\varepsilon_0 r}$ or $V \propto \frac{1}{r}$

and electric field, $E = \frac{Q}{4\pi\varepsilon_0 r^2}$ or $E \propto \frac{1}{r^2}$

Thus, electric potential shows an inverse relationship while electric field shows an inverse square relationship with r.

So, their corresponding plots would be



129. Explain why, for any configuration, the equipotential surface through a point is normal to the electric field at the point.

Draw a sketch of equipotential surfaces due to a single charge $(-q)$, depicting the electric field lines due to the charge.

Ans : **Main 2024, 2011**

The work done in moving a charge from one point to another on an equipotential surface is zero. If the field is not normal to an equipotential surface, it would have a non zero component along the surface. This would imply that work would have to be done to move a charge on the surface which is contradictory to the definition of equipotential surface.

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Mathematically

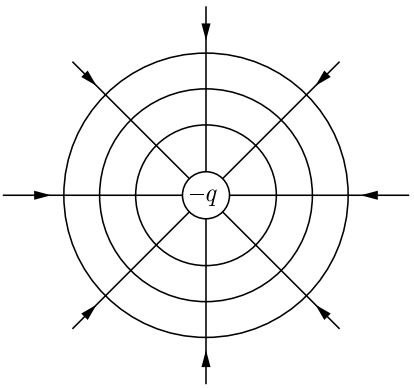
Work done to move a charge dq, on a surface, can expressed as

$$dW = dq(\vec{E} \cdot \vec{dr})$$

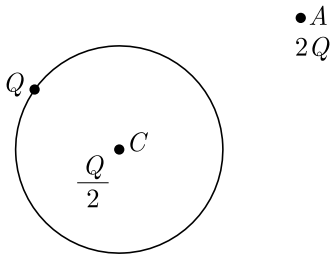
But $dW = 0$ on an equipotential surface

Hence, $\vec{E} \perp \vec{dr}$

Equipotential surfaces for a charges $-q$



130. A thin metallic spherical shell of radius R carries a charge Q on its surface. A point charge $\frac{Q}{2}$ is placed at its centre C and an other charge $+2Q$ is placed outside the shell at a distance x from the centre as shown in the figure. Find (a) the force on the charge at the centre of shell and at the point A, (b) the electric flux through the shell.



Ans : **Main 2013**

(a) At point C, inside the shell.

The electric field inside a spherical shell is zero. Thus, the force experienced by charge at the centre C will also be zero.

$$F_C = qE \ (E_{\text{inside the shell}} = 0)$$

$$F_C = 0$$

At point A,

$$|F_A| = 2Q\left(\frac{1}{4\pi\varepsilon_0}\frac{3Q/2}{x^2}\right)$$

$$F = \frac{3Q^2}{4\pi\varepsilon_0 x^2}, \text{ away from shell}$$

(b) Electric flux through the shell

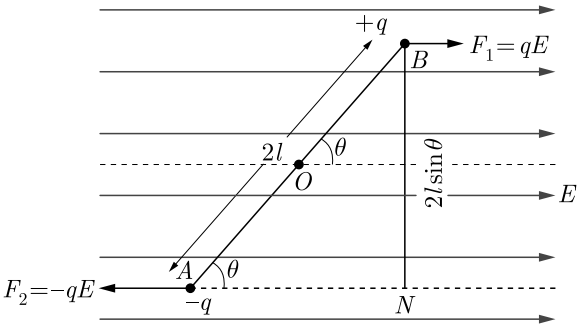
$\phi = \frac{1}{\varepsilon_0}x$ magnitude of the charge enclosed by the shell.

$$\phi = \frac{1}{\varepsilon_0} \times \frac{Q}{2} = \frac{Q}{2\varepsilon_0}$$

131. Show that the potential energy of a dipole making angle θ with the direction of the field is given by $u(\theta) = -\vec{p} \cdot \vec{E}$. Hence, find out the amount of work done in rotating it form the position of unstable equilibrium to the stable equilibrium.

Ans : **Main 2025**

As charges $+q$ and $-q$ traverse equal distance under equal an opposite forces; therefore, not work done in bringing the dipole in the region of electric field perpendicular to field-direction will be zero, i.e., $W_1 = 0$.



Now, the dipole is rotated and brought to orientation making an angle θ with the field direction (i.e., $\theta_0 = 90^\circ$ and $\theta_1 = \theta^\circ$). Therefore, work done

$$W_2 = pE(\cos\theta_0 - \cos\theta_1)$$

$$= pE(\cos 90^\circ - \cos\theta)$$

$$= -pE\cos\theta$$

Hence, Total wore done in bringing the electric dipole from infinity, i.e., electric potential energy of electric dipole. Thus, work done by external torque in rotating a dipole in uniform electric field is stored as the potential energy of the system.

$$U = W_1 + W_2 = 0 - pE\cos\theta$$

$$= -pE\cos\theta$$

In vector from, $U = -\vec{p} \cdot \vec{E}$

For rotating dipole from position of unstable equilibrium ($\theta_0 = 180^\circ$) to the stable equilibrium ($\theta = 0^\circ$).

Hence, $W_{\text{req}} = pE(\cos 180^\circ - \cos 0^\circ)$

$$= pE(-1-1) = -2pE$$

132. Find out the expression electrostatic potential due to a point charge?

Ans : **Main 2019**

Let Ps be the point at a distance r from the origin O at which the electric potential due to charge $+q$ is required.

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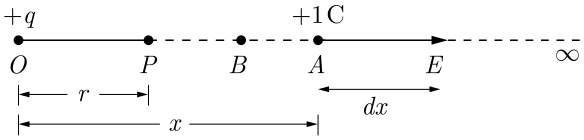


The electric potential at a point P is the amount of work done in carrying a unit positive charge from ∞ to P. As, work done is independent of the path, we choose a convenient path along the radial direction from infinity to the point P without acceleration. Let A be an intermediate point on this path where $OA = x$. The electrostatic force on a unit positive charge at A is given by,

$$F = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q \times 1}{x^2} \qquad [\text{along } OA]$$

Small work done in moving the charge through a distance dx from A to B is given by,

$$\begin{aligned} dW &= F \cdot dx = Fdx\cos 180^\circ \\ &= -Fdx \qquad [\text{Since, } \cos 180^\circ = -1] \\ &= -Fdx \end{aligned}$$

Total work done in moving a unit positive charge from ∞ to the point P is given by,

$$\begin{aligned} W &= \int_\infty^r -Fdx = \int_\infty^r -\frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{x^2} dx \\ &= -\frac{q}{4\pi\varepsilon_0}\int_\infty^r x^{-2} dx \\ &= -\frac{q}{4\pi\varepsilon_0}\left[\frac{-1}{x}\right]_\infty^r \left[\text{since } \int x^{-2}dx = -\frac{1}{x}\right] \\ &= -\frac{q}{4\pi\varepsilon_0}\left[\frac{1}{r} - \frac{1}{\infty}\right] = \frac{q}{4\pi\varepsilon_0 r} \end{aligned}$$

From the definition of electric potential, this work is equal to the potential at point P.

$$V = \frac{q}{4\pi\varepsilon_0 r}$$

133. A slab of material of dielectric constant K has the same area as that of the plates of a parallel plate capacitor but has the thickness $d/2$, where d is the separation between the plates. Find out the expression for its capacitance when the slab is inserted between the plates of the capacitor.

Ans : **SQP 2021**

Initially when there is vacuum between the two plates, the capacitance of the two-parallel plates is,

$$C_0 = \frac{\varepsilon_0 A}{d}$$

where, A is the area of parallel plates.

Suppose that the capacitor is connected to a battery, an electric field E_0 is produced.

Now, if we insert the dielectric slab of thickness $t = d/2$, the electric field reduces to E.

Now, the gap between plates is divided in two parts, for distance t there is electric field E and for the remaining distance $(d - t)$ the electric field is E_0.

If V be the potential difference between the plates of the capacitor, then

$$\begin{aligned} V &= E_t + E_0(d - t) \\ &= \frac{Ed}{2} + \frac{E_0 d}{2} \\ &= \frac{d}{2}(E + E_0) \qquad \left(\because\ t = \frac{d}{2}\right) \\ &= \frac{d}{2}\left(\frac{E_0}{K} + E_0\right) \\ &= \frac{dE_0}{2K}(K + 1) \qquad \left(\text{As}, \frac{E_0}{E} = K\right) \end{aligned}$$

$$E_0 = \frac{\sigma}{\varepsilon_0} = \frac{q}{\varepsilon_0 A}$$

$$V = \frac{d}{2K} \cdot \frac{q}{\varepsilon_0 A}(K + 1)$$

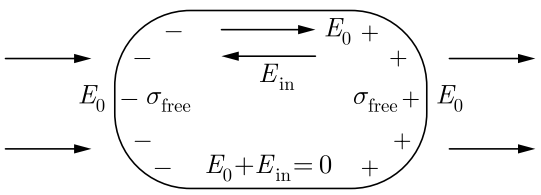
$$C = \frac{q}{V} = \frac{2K\varepsilon_0 A}{d(K + 1)}$$

134. Explain, using suitable diagram, the difference in the behaviour of a

1. Conductor
2. Dielectric in the presence of external electric field. Define the terms polarisation of a dielectric and write its relation with susceptibility.

Ans : **Main 2017**

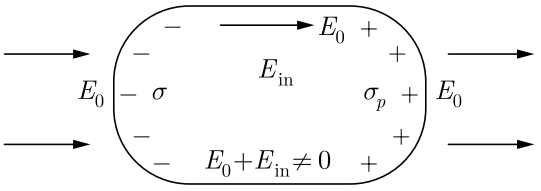
1. When a capacitor is placed in an external electric field, the free charges present inside the conductor redistribute themselves in such a manner that the electric field due to induced charges opposes the external field within the conductor. This happens until a static situation is achieved, i.e. When the two fields cancel each other and the net electrostatic field in the conductor becomes zero.



Conductor

2. In contrast to conductors, dielectrics are non-conducting substances, i.e. they have no charge carriers. Thus, in a dielectric, free movement

of charges in not possible. It turns out that the external field induces dipole moment by stretching molecular of the dielectric. The collective effect of all the molecular dipole moments is the net charge on the surface of he dielectric which produces a field that opposes the external field. However, the opposing field is so induced, that does not exactly cancel the external field. It only reduces it. The extent of the effect depends on the nature of dielectric.



Dielectric

Both polar and non-polar dielectrics develop net dipole moment in the presence of an external field. The dipole moment per unit volume is called polarisation and is denoted by P for linear isotropic dielectrics.

$$p = \chi E$$

Where χ is constant of proportionality and is called electric susceptibility of the electric slab.

135. Find an expression for capacity of a parallel plate capacitor with compound dielectric.

Ans : **Comp 2024, 2014**

Consider a parallel plate capacitor of plate area A and plate separation d. If the space between the plates is vacuum, its capacitance is given by,

$$C_0 = \frac{\varepsilon_0 A}{d}$$

Suppose initially the charge on the capacitor plates are $\pm Q$. Then the uniform electric field set up between the capacitor plates is,

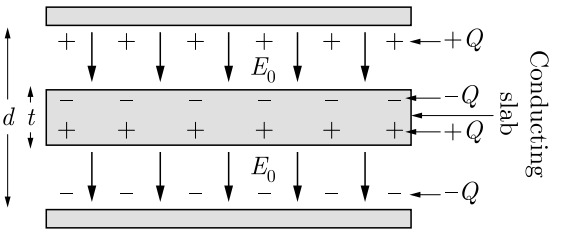
$$E_0 = \frac{\sigma}{\varepsilon_0} s = \frac{Q}{A\varepsilon_0}$$

where σ is the surface charge density. The potential difference between the capacitor plates will be,

$$V_0 = E_0 d = \frac{Qd}{A\varepsilon_0}$$

When a conducting slab of thickness $t < d$ is placed between the capacitor plates, free electrons flow inside it so as to reduce the field to zero inside the slab, as shown in Figure. Charges - Q and $+Q$ appear on the upper and lower faces of the slab. Now the electric field exists only in the vacuum region between the plates of the capacitor on the either side of the slab, i.e. the field exists only in thickness $d - ts$, therefore, potential difference between the plates of the capacitor is,

$$V = E_0(d-t) = \frac{Q}{A\varepsilon_0}(d-t)$$



Hence, Capacitance of the capacitor in the presence of conducting slab becomes,

$$C = \frac{Q}{V} = \frac{\varepsilon_0 A}{(d-t)}$$

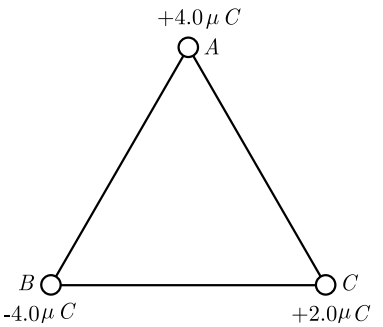
$$= \frac{\varepsilon_0 A}{d} \cdot \frac{d}{d-t}$$

or $$C = \left(\frac{d}{d-t}\right) \cdot C_0$$

Clearly, $C > C_0$. Thus the introduction of a conducting slab of thickness t in a parallel plate capacitor increases its capacitance by a factor of $\frac{d}{d-t}$.

136. State the significance of negative value of electrostatic potential energy of a system of charges.

There charges are placed at the corners of an equilateral triangle ABC of side 2.0 m as shown in figure. Calculate the electric potential energy of the system of three charges.



Ans : **Main 2023**

The expression for electric potential due to a point charge is,

$$V = k\frac{q}{r}$$

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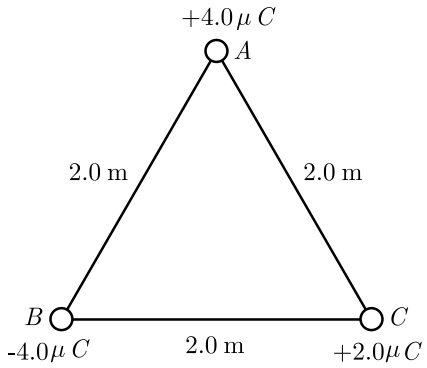
The electric potential is a scalar quantity. Since, both the charges are positive, therefore, the electric potential at any point is the sum of the electric potentials of both the charges, which is a positive quantity. Thus, the electric potential along the line joining of two equal positive charges cannot be zero.

A negative value of electrostatic potential energy means that work must be done against the electric field in moving the charges apart.



Formula of electrostatic potential energy,

$$U_E = k\frac{q_1 q_2}{r}$$

Now, total

$$P.E. = PE._{AB} + PE._{Bc} + PE._{Ac}$$

$$k = \left[\frac{4\times(-4)}{2} + \frac{(-4)\times 2}{2} + \frac{(4)\times(2)}{2}\right]\times 10^{-12}$$

$$= k\left[\frac{-16}{2} + \frac{-8}{2} + \frac{8}{2}\right]\times 10^{-12}$$

$$= -8k\times 10^{-12}$$

$$= -8\times 9\times 10^{9}\times 10^{-12}$$

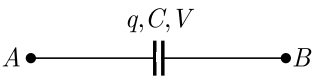
$$= -72\times 10^{-3} = -7.2\times 10^{-2}\,\text{J}$$

137. A fully charged parallel plate capacitor is connected across an uncharged identical capacitor. Show that the energy stored in the combination is less than stored initially in the single capacitor.

Ans : **SQP 2016**

Initial condition,

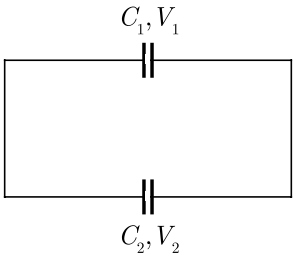
If we consider a charge capacitor, then its charge would be given $q = CV$.



and energy stored in it is given by

$$U_1 = \frac{1}{2}CV^2 \qquad ...(1)$$

When this charged capacitor is connected to uncharged capacitor,



Let the common potential be V_1, the charge flow from first capacitor to the other capacitor unless both the capacitor attained the common potential.

$$Q_1 = CV_1$$

and $$Q_2 = CV_2$$

Applying conservation of charge,

$$Q = Q_1 + Q_2$$

$$CV = CV_1 + CV_2$$

$$V = V_1 + V_2$$

$$V_1 = \frac{V}{2}$$

Total energy stored on both the capacitor

$$U_2 = \frac{1}{2}CV_1^2 + \frac{1}{2}CV_1^2$$

$$U_2 = \frac{1}{2}C\left(\frac{V}{1}\right)^2 + \frac{1}{2}C\left(\frac{V}{2}\right)^2$$

$$U_2 = \frac{2CV^2}{8} = \frac{1}{4}CV^2 \qquad ...(2)$$

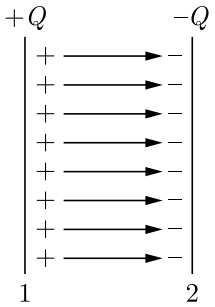
From equations (1) and (2), we get

$$U_2 < U_1$$

It means that energy stored in the combination is less than that stored initially in the single capacitor.

138. erive the expression for the energy stored in parallel plate capacitor. Hence, obtain the expression for the energy density of the electric field.

Ans : **Main 2015**



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In order to calculate the energy stored in this charge configuration, suppose the conductors 1 and 2 are initially uncharged. Let positive charge be transferred from conductor 2 to conductor 1 in very small instalments of dq each till conductor 1 get charge $+Q$. By charge conservation, conductor 2 would get charge $-Q$.

At every stage of charging, conductor 1 is at higher potential than conductor 2. Therefore, work is done externally in transferring each instalment of charge.

Hence, Potential difference between conductor 1 and 2 is $\frac{q}{C}$

Hence, Potential of condenser $= \frac{q}{C}$

Small amount of work done in giving an additional charge dq to the condenser is $dW = \frac{q}{C} \times dq$

Hence, Total work done in giving a charge Q to the condenser,

$$W = \int_{q=0}^{q=Q} \frac{q}{C} = \frac{1}{C}\left[\frac{q^2}{2}\right]_{q=0}^{q=Q}$$

$$W = \frac{1}{C}\frac{Q^2}{2}$$

As, electrostatic force is conservative, this work is stored in the form of potential energy (U) of the condenser.

$$U = W = \frac{1}{2}\frac{Q^2}{C}$$

$$Q = CV$$

$$U = \frac{1}{2}\frac{(CV)^2}{C} = \frac{1}{2}CV^2$$

$$CV = Q$$

$$U = \frac{1}{2}QV$$

$$U = \frac{1}{2}\frac{Q^2}{C} = \frac{1}{2}CV^2 = \frac{1}{2}QV$$

Energy density (U) is defined as the total energy per unit volume of the condenser.

i.e., $$u = \frac{\text{Total energy (U)}}{\text{Volume (V)}}$$

$$= \frac{\frac{1}{2}CV^2}{Ad}$$

Using, $$C = \frac{\varepsilon_0 A}{d}$$

and $$V = Ed$$

We get, $$U = \frac{1}{2}\left(\frac{\varepsilon_0 A}{d}\right)\left(\frac{E^2 d^2}{Ad}\right) = \frac{1}{2}\varepsilon_0 E^2$$

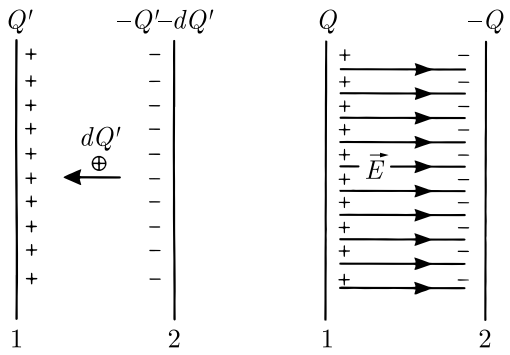
Hence, E is the strength of electric field in the space between the plates of the capacitor.

139. Derive expression for stored energy between plates of parallel plate capacitor. Show that energy-density between plates of the capacitor can be expressed as $1/2\,\varepsilon_0\ E^2$, when E = Electric field between plates.

Ans : **SQP 2008, 2006**

Expression for the Energy Stored in a Capacitor : Consider a capacitor of capacitance C. Initially, its two plates are uncharged. Suppose the positive charge is transferred from plate 2 to plate 1 bit by bit. In this process, external work has to be done because at any stage plate 1 is at higher potential than the plate 2. Suppose at any instant the plates 1 and 2 have charges Q' and $-Q'$ respectively, as shown in Figure (a). Then the potential difference between the two plates will be

$$V' = \frac{Q'}{C}$$



(a) **(b)**

Suppose now a small additional charged dQ' be transferred from plate 2 to plate 1. The work done will be,

$$dW = V' \cdot dQ' = \frac{Q'}{C} \cdot dQ'$$

The total work done in transferring a charge Q from plate 2 to plate 1 (Figure b) will be,

$$W = \int dW = \int_0^Q \frac{Q'}{C} \cdot dQ'$$

$$= \left[\frac{Q'^2}{2C}\right]_0^Q = \frac{1}{2} \cdot \frac{Q^2}{C}$$

This work done is stored as electrical potential energy U of the capacitor.

$$U = \frac{1}{2} \cdot \frac{Q^2}{C} = \frac{1}{2} \cdot CV^2$$

$$= \frac{1}{2}QV \qquad (\text{Since}, Q = CV)$$

Energy Density between Plates of Capacitor

Capacitance of the parallel plate capacitor is given by,

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$$C = \frac{\varepsilon_0 A}{d} \quad ...(1)$$

If σ is the surface charge density on the capacitor plates, then electric field between the capacitor plates will be,

$$E = \frac{\sigma}{\varepsilon_0}$$

$$\sigma = \varepsilon_0 E$$

Charge on either plate of capacitor is,

$$Q = \sigma A = \varepsilon_0 EA \quad ...(2)$$

Hence, Energy stored in the capacitor is,

$$U = \frac{Q^2}{2C} = \frac{(\varepsilon_0 EA)^2}{2 \cdot \frac{\varepsilon_0 A}{d}}$$

[From Eq. (1) and (2)]

$$= \frac{1}{2}\varepsilon_0 E^2 Ad$$

But $Ad =$ volume of the capacitor between its two plates. Therefore, the energy stored per unit volume or the energy density of the electric field is given by,

$$u = \frac{U}{Ad} = \frac{1}{2}\varepsilon_0 E^2$$

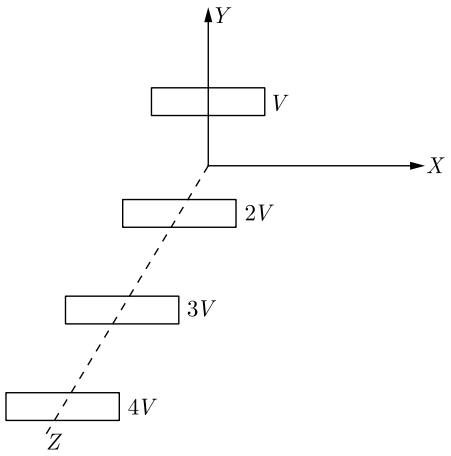
140. Draw schematically equipotential surfaces corresponding to

1. A constant electric field in Z-direction.
2. A field that uniformly increases in magnitude but remains in a constant (say Z) direction.
3. A single positive charge at the origin.
4. A uniform grid consisting of long equally spaced parallel charged wires in a plane.

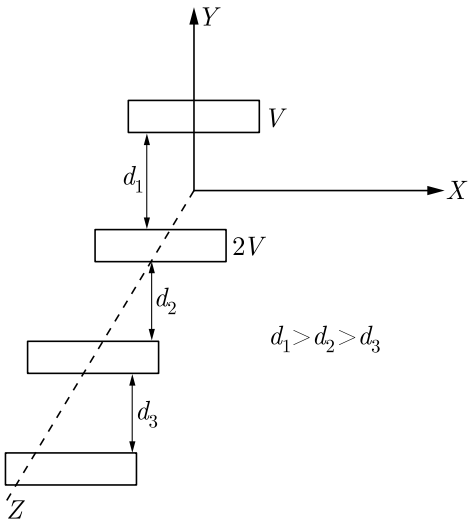
Ans : **SQP 2013**

Equipotential surface is a surface having the same potential at each of its points. In the given cases the equipotential surface are

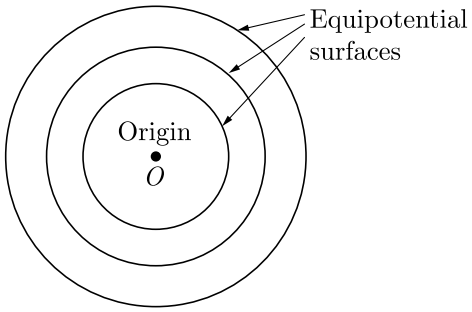
1. The planes parallel to XY plane. For some potential difference, the planes are equidistant.



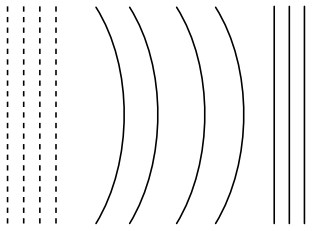
2. The planes are parallel to XY plane, but for the same potential difference, the separation between the planes decreases.



3. Concentric spheres centred at the origin.



4. A periodically varying shape near the grid which gradually attains the shape of planes parallel to grid at far distance.



141. Derive an expression for the capacitance of a parallel plate capacitor. If a compound dielectric medium is introduced between the plates of the capacitor, how will the capacitance of the capacitor change?

Ans : **Main 2015**

The simplest and the most widely used capacitor is the parallel plate capacitor. It consists of two large plane parallel conducting plates, separated by a small distance.

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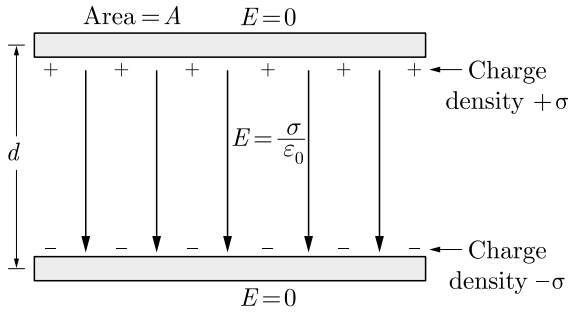
Let, A = area of each plate,

d = distance between the two plates

$\pm\sigma$ = uniform surface charge densities on the two plates

$\pm Q = \pm\sigma A$

= total charge on each plate



Parallel plate capacitor

In the outer regions above the upper plate and below the lower plate, the electric field due to the two charged plates cancel out. The net field is zero.

$$E = \frac{\sigma}{2\varepsilon_0} - \frac{\sigma}{2\varepsilon_0} = 0$$

In the inner region between the two capacitor plates, the electric fields due to the two charged plates add up. The net field is

$$E = \frac{\sigma}{2\varepsilon_0} + \frac{\sigma}{2\varepsilon_0} = \frac{\sigma}{\varepsilon_0}$$

The direction of the electric field is form the positive to the negative plate and the field is uniform throughout. For plates with finite area, the field lines bend at the edges. This effect is called fringing of the field. But for large plates separated by small distance ($A >> d^2$), the field is almost uniform in the regions far from the edges. For a uniform electric field,

Potential difference between the plates

= Electric field × distance between the plates

$$V = Ed = \frac{\sigma d}{\varepsilon_0}$$

Capacitance of the parallel plate capacitor is

$$C = \frac{Q}{V} = \frac{\sigma A}{\sigma d/\varepsilon_0} \text{ or } C = \frac{\varepsilon_0 A}{d}$$

Capacitance of a Parallel Plate Capacitor with a Dielectric Slab

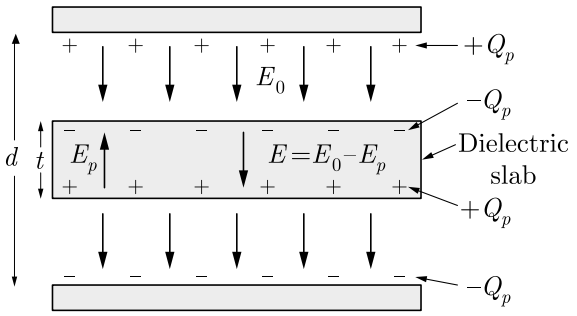
The capacitance of a parallel plate capacitance of plate area A and plate separation d with vacuum between its plates is given by,

$$C_0 = \frac{\varepsilon_0 A}{d}$$

Suppose initially the charges on the capacitor plates are $\pm Q$. Then the uniform electric field set up between the capacitor plates is,

$$E_0 = \frac{\sigma}{\varepsilon_0} = \frac{Q}{A\varepsilon_0}$$

When, a dielectric slab of thickness $t < d$ is placed between the plates, the field E_0 polarises the dielectric. This induces charge $-Q_P$ on the upper surface and



$+Q_p$ on the lower surface of the dielectric. These induced charges set up a field E_p inside the dielectric in the opposite direction of $\vec{E}_0$. The induced field is given by,

$$E_p = \frac{\sigma_p}{\varepsilon_0} = \frac{P}{\varepsilon_0}$$

$$\left[\sigma_P = \frac{Q}{A} = P, \text{Polarisation density}\right]$$

The net field inside the dielectric is,

$$E = E_0 - E_p = \frac{E_0}{k}\left[\text{Since}, \frac{E_0}{E_0 - E_p} = k\right]$$

where k is the dielectric constant of the slab. So between the capacitor plates, the field E exists over a distance t and field E_0 exists over the remaining distance $(d-t)$. Hence the potential difference between the capacitor plates is,

$$V = E_0(d-t) + Et$$

$$= E_0(d-t) + \frac{E_0}{k}t \quad \left[\text{Since}, \frac{E_0}{E} = k\right]$$

$$= E_0\left(d - t + \frac{t}{k}\right)$$

$$= \frac{Q}{\varepsilon_0 A}\left(d - t + \frac{t}{k}\right)$$

The capacitance of the capacitor on introduction of dielectric slab becomes,

$$C = \frac{Q}{V} = \frac{\varepsilon_0 A}{d - t + \frac{t}{k}}$$

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NUMERICAL QUESTIONS

142. A 12 pF capacitor is connected to a 50 V battery. How much electrostatic energy is stored in the capacitor ?

Ans : **Main 2013**

Given, $C = 12\,\text{pF}$

$= 12 \times 10^{-12}\,\text{F}$

and $V = 50\,\text{V}$, $U = ?$

$$U = \frac{1}{2}CV^2$$

$$= \frac{1}{2} \times 12 \times 10^{-12} \times (50)^2$$

$$= 1.5 \times 10^{-8}\,\text{J}$$

143. Calculate electric potential at a point P which is at a distance of 9 cm from a point charge of 50 μC

Ans : **Main 2023**

Given, $r = 9 \times 10^{-2}\,\text{m}$

$Q = 50 \times 10^{-6}\,\text{C}$

$$V = \frac{kQ}{r} \qquad [k = 9 \times 10^9]$$

$$V = \frac{9 \times 10^9 \times 50 \times 10^{-6}}{9 \times 10^{-2}}$$

$$= 5 \times 10^7\,\text{V}$$

Electric potential $= 5 \times 10^7\,\text{V}$

144. A parallel plate air capacitor has a capacitance of 5 μF. It becomes 50 μF when a dielectric medium occupies the entire space between its two plates. What is the dielectric constant of the medium?

Ans : **Main 2025**

Capacitance in air, $C_0 = 5\,\mu\text{F}$

Capacitance with dielectric, $C = 50\,\mu\text{F}$

$$\text{Dielectric constant, } K = \frac{C}{C_0}$$

$$= \frac{50\,\mu\text{F}}{5\,\mu\text{F}} = 10$$

145. Two point charges of 10 C each, are kept at a distance of 3 m in vacuum. Calculate their electrostatic potential energy.

Ans : **Main 2015, 2013**

$q_1 = 10\,\text{C}$, $q_2 = 10\,\text{C}$, distance between charges $a = 3\,\text{m}$

Electrostatic potential energy is given by

$$U = \frac{1}{4\pi\varepsilon_0} \times \frac{q_1 q_2}{a} \qquad ...(1)$$

Here, $\dfrac{1}{4\pi\varepsilon_0} = 9 \times 10^9$

Substituting the all values in Eq. (1), we get

$$U = 9 \times 10^9 \times \frac{10 \times 10}{3}$$

$$U = 3 \times 10^{11}\,\text{J}$$

146. How much kinetic energy is gained by an electron, initially at rest, when it moves through a potential difference of 1000 V? Give your answer in joule.

Ans : **Main 2008**

From conservation of mechanical energy

Change in PE = Gain in KE

$$\Delta U = \Delta K \Rightarrow \text{eV} = \frac{1}{2}\,\text{mv}^2$$

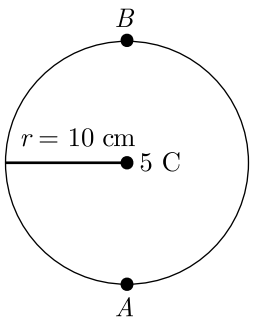
Where, V is potential difference and e is electronic charge, m is the mass and v is the speed of the electron.

$$\Delta K = eV$$

$$= 1.6 \times 10^{-19} \times 1000$$

$$= 1.6 \times 10^{-16}\,\text{J}$$

147. A charge of 5 C is placed at the centre of a circle of radius 10 cm as shown in the figure alongside. Calculate the work done in moving a charge of 2 C from point A to B on the circumference of the circle.



Ans : **Main 2005**

This circular surface acts as equipotential surface.

Hence, work done in moving the

2 C charge from A to B

$$W_{A \to B} = (2\,\text{C})(V_{AB})$$

$$= (2\,\text{C})(V_B - V_A) = 0 \qquad [V_B = V_A]$$

148. Net capacitance of three identical capacitors in series is 1 μF. What will be their net capacitance if connected in parallel ? Find the ratio of energy stored in the two configurations if they are both connected to the same source.

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Ans : **Main 2015**

Let each capacitor have a capacitance C. Then in series, we have

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} = \frac{3}{C} = 1\,\mu\text{F}$$

or $$C = 3\,\mu\text{F}$$

Hence, in parallel, we have

$$C_P = C_1 + C_2 + C_3$$
$$= 3 + 3 + 3 = 9\,\mu\text{F}$$
$$\frac{E_S}{E_P} = \frac{\frac{1}{2} C_S V^2}{\frac{1}{2} C_P V^2} = \frac{C_S}{C_P} = \frac{1}{9}$$

149. A 600 pF capacitor is charged by a 200 V supply. It is then disconnected from the supply and is connected to another uncharged 600 pF capacitor. How much electrostatics energy is lost in the process ?

Ans : **SQP 2024**

Given, $$C_1 = C_2 = 600\,\text{pF}$$
$$= 600 \times 10^{-12}\,\text{F}$$
$$V = 200\,\text{Volt}$$
$$\Delta U = ?$$

Using the relation

$$\Delta U = \frac{C_1 C_2 (V_1 - V_2)^2}{2(C_1 + C_2)}, \text{ we get}$$
$$\Delta U = \frac{600 \times 600 \times 10^{-24} (200 - 0)^2}{2(600 + 600) \times 10^{-12}}$$
$$= 6 \times 10^{-6}\,\text{J}$$

150. Net capacitance of three identical capacitors in series is 1 μF. What will be their net capacitance if connected in parallel? Find the ratio of energy stored in the two configurations if they are both connected to the same source.

Ans : **SQP 2015**

Let each capacitor have a capacitance C. Then in series, we have,

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} = \frac{3}{C} = 1\mu\text{F}$$
$$C_S = 3\mu\text{F}$$

Hence, in parallel, we have

$$C_P = C_1 + C_2 + C_3$$
$$= 3 + 3 + 3 = 9\mu\text{F}$$
$$\frac{E_S}{E_P} = \frac{\frac{1}{2} C_S V^2}{\frac{1}{2} C_P V^2} = \frac{C_S}{C_P} = \frac{1}{9}$$

151. What is the work done in placing a charge of 8×10^{-18} C on a capacitor of capacity of capacity 100 μF ?

Ans : **SQP 2014, 2012**

Charge, $$q = 8 \times 10^{-18}\,\text{C}$$

and capacity of capacitor,

$$C = 100\,\mu\text{F} = 100 \times 10^{-6}\,\text{F}$$

Potential developed due to the charge,

$$V = \frac{q}{C} = \frac{8 \times 10^{-18}}{100 \times 10^{-6}}$$
$$= 8 \times 10^{-14}\,\text{V}$$

Therefore, work done,

$$W = \frac{1}{2} CV^2$$
$$= \frac{1}{2} \times (100 \times 10^{-6}) \times (8 \times 10^{-14})^2$$
$$= 32 \times 10^{-32}\,\text{J}$$

152. A metallic sphere of radius 9 cm has been given a charge of 4×10^{-6} C. Calculate energy of charged conductor.

Ans : **Main 2025**

Radius of metallic sphere,

$$r_s = 9\,\text{cm}$$
$$= 9 \times 10^{-2}\,\text{m}$$

Charge on sphere, $q = 4 \times 10^{-6}\,\text{C}$

Now, Energy of charged conductor is given by,

Energy, $$E = \frac{1}{2} qV$$

Potential, $$V = \frac{1}{4\pi\varepsilon_0} \frac{q}{r}$$

So, $$E = \frac{1}{2} q \times \left(\frac{1}{4\pi\varepsilon_0} \times \frac{q}{r} \right)$$

$$\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9 \frac{\text{N-m}^2}{\text{C}^2}$$

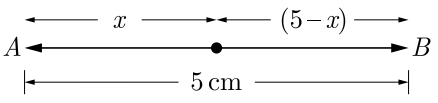
$$E = \frac{1}{2} \times 4 \times 10^{-6} \times 9 \times 10^9 \times \frac{4 \times 10^{-6}}{9 \times 10^{-2}}$$

$$= 0.8\,\text{J}$$

153. Two charges 2 μC and −2 μC are placed at points A and B, 5 cm apart. Depict an equipotential surface of the system.

Ans : **Main 2013**

Given, $$q_A = 2\,\mu\text{C} = 2 \times 10^{-6}\,\text{C}$$
$$q_B = -2\,\mu\text{C} = -2 \times 10^{-6}\,\text{C}$$



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and $r = 5\,\text{cm}$

Potential, $V = \dfrac{2\times10^{-6}}{4\pi\varepsilon_0 x\times10^{-2}} + \dfrac{-2\times10^{-6}}{4\pi\varepsilon_0(5-x)\times10^{-2}}$

$$\frac{2\times10^{-6}}{4\pi\varepsilon_0 x\times10^{-2}} = \frac{2\times10^{-6}}{4\pi\varepsilon_0(5-x)\times10^{-2}} \quad [\text{since } V=0]$$

$$x = 5 - x$$

$$x = 2.5$$

154. Evaluate the capacitance of a parallel plate capacitor, having parallel plates of area $6\,\text{cm}^2$ placed at a separation of 2 mm. Consider air between plates as a dielectric medium. If the capacitor is connected to 200 V power supply. What will be the charge on each plate?

Ans : **SQP 2018**

Area of Plate, $A = 6\,\text{cm}^2 = 6\times10^{-4}\text{m}^2$

Distance between plates,

$$d = 2\,\text{mm} = 2\times10^{-3}\text{m}$$

Capacitance of parallel plate capacitor,

$$C = \frac{\varepsilon_0 A}{d}$$

$$= \frac{8.85\times10^{-12}\times6\times10^{-4}}{2\times10^{-3}}$$

$$= 2.655\times10^{-12}\text{F}$$

Charge, $Q = CV$

$$= 2.655\times10^{-12}\times200$$

$$= 5.31\times10^{-10}\text{C}$$

$$= 0.531\times10^{-9}\text{C} = 0.531\,\text{nC}$$

155. Three capacitors each of capacitance 9 pF are Net capacitance of three identical capacitors in series is $1\,\mu\text{F}$. What will be their net capacitance if connected in parallel ? Find the ratio of energy stored in the two configurations if they are both connected to the same source.

Ans : **Main 2018**

Let C be the capacitance of each capacitor, then in series,

$$\frac{1}{C_S} = \frac{1}{C}+\frac{1}{C}+\frac{1}{C} = \frac{3}{C}$$

or $C = 3C_S = 3\times1\,\mu\text{F} = 3\,\mu\text{F}$

When these capacitors are connected in parallel, net capacitance,

$$C_P = 3C = 3\times3 = 9\,\mu\text{F}$$

When these two combinations are connected to same source the potential difference across each combination is same.

Ratio of energy stored,

$$\frac{U_S}{U_P} = \frac{\frac{1}{2}C_S V^2}{\frac{1}{2}C_P V^2} = \frac{C_S}{C_P} = \frac{1\,\mu\text{F}}{9\,\mu\text{F}} = \frac{1}{9}$$

$$U_S : U_P = 1:9$$

156. Net capacitance of three identical capacitors in series is $1\,\mu\text{F}$. What will be their net capacitance if connected in parallel? Find the ratio of energy stored in the two configurations if they are both connected to the same source.

Ans : **SQP 2017, 2015**

Let C be the capacitance of each capacitor, then in series,

$$\frac{1}{C_S} = \frac{1}{C}+\frac{1}{C}+\frac{1}{C} = \frac{3}{C}$$

$$C = 3C_S = 3\times1\,\mu\text{F} = 3\,\mu\text{F}$$

When these capacitors are connected in parallel, net capacitance,

$$C_P = 3C = 3\times3 = 9\,\mu\text{F}$$

When these two combinations are connected to same source the potential difference across each combination is same.

Ratio of energy stored,

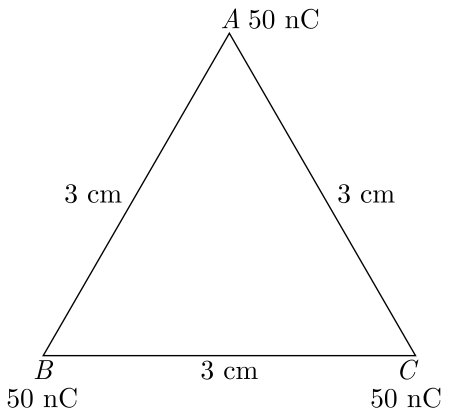
$$\frac{U_S}{U_P} = \frac{\frac{1}{2}C_S V^2}{\frac{1}{2}C_P V^2} = \frac{C_S}{C_P}$$

$$= \frac{1}{9}$$

$$U_S : U_P = 1:9$$

157. Three point charges of 50 nC each are kept at the vertices of an equilateral triangle having each side = 3 m. Calculate electrostatic potential energy of the system.

Ans : **Main SQP 2023**



$$U = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1 q_2}{r}+\frac{q_2 q_3}{r}+\frac{q_3 q_1}{r}\right)$$

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$$= 9 \times 10^9 \times \left(\begin{array}{l} \frac{50 \times 10^{-19} \times 50 \times 10^{-9}}{3} \\ + \frac{50 \times 10^{-9} \times 50 \times 10^{9}}{3} \\ + \frac{50 \times 10^{-9} \times 50 \times 10^{-9}}{3} \end{array} \right)$$

$$= 9 \times 10^9 \times 2.5 \times 10^{15}$$

$$U = 2.25 \times 10^5 \text{ J}$$

158. An electron revolves around the nucleus of hydrogen atom in a circular orbit of radius 5×10^{-11} m. Calculate

(i) intensity of electric field of the nucleus at the position of the electron.

(ii) electrostatic potential energy of the hydrogen nucleus and electron system.

Ans : **Main 2010**

Radius of the orbit,

$$r = 5 \times 10^{-11} \text{ m}$$

$$\text{Charge} = + e = 1.6 \times 10^{-19} \text{ C}$$

(i) Intensity of electric field,

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$$

$$= 9 \times 10^9 \times \frac{1.6 \times 10^{-19}}{(5 \times 10^{-11})^2}$$

$$= 5.76 \times 10^{10} \text{ NC}^{-1}$$

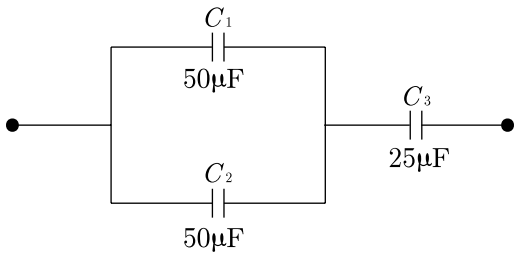
(ii) Electrostatic potential energy of the system,

$$U = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r}$$

$$= \frac{9 \times 10^9 \times 1.6 \times 10^{-19} \times (-1.6 \times 10^{-19})}{5 \times 10^{-11}}$$

$$= -4.608 \times 10^{-18} \text{ J}$$

159. Calculate equivalent capacitance of the circuit shown in figure given below.



Ans : **Main 2023**

From the given circuit

C_1 and C_2 are in parallel and C_3 is in series with C_1 and C_2.

$$C_1 + C_2 = 50\,\mu\text{F} + 50\,\mu\text{F} = 100\,\mu\text{F}$$

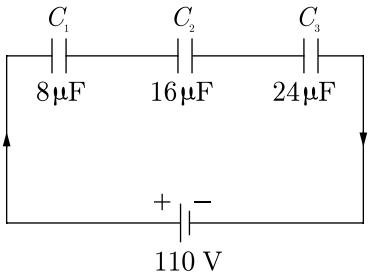
Now, $(C_1 + C_2)$ series with C_3 therefore the equivalent capacitance of the circuit

$$= \frac{(C_1 + C_2)C_3}{(C_1 + C_2) + C_3}$$

$$= \frac{100\,\mu\text{F} \times 25\,\mu\text{F}}{100\,\mu\text{F} + 25\,\mu\text{F}}$$

$$= \frac{2500\,\mu\text{F}}{125\,\mu\text{F}} = 20\,\mu\text{F}$$

160. Find the electric charge Q_1 on plates of capacitor C_1, shown in figure below.



Ans : **Main 2009, 2007**

According to the given circuit diagram all capacitors are in series. So the equivalent capacitance is given by

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$\frac{1}{C} = \frac{1}{8} + \frac{1}{16} + \frac{1}{24}$$

$$\frac{1}{C} = \frac{6 + 3 + 2}{48} = \frac{11}{48}$$

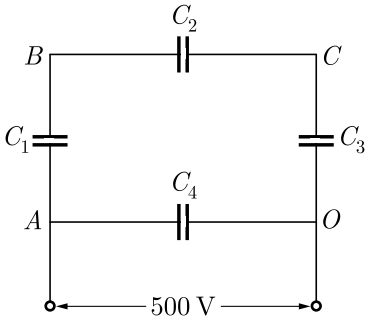
$$C = \frac{48}{11}\,\mu\text{F}$$

Now, Charge on each capacitor,

$$Q = CV$$

$$= \frac{48}{11} \times 110 = 480\,\mu\text{C}$$

161. A network of four capacitors each of $12\,\mu\text{F}$ capacitance is connected a 500 Volt supply as shown in the figure. Determine equivalent capacitance of the network.



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Ans : SQP 2012

The equivalent circuit is shown in figure.

$$C_1 = C_2 = C_3 = C_4 = 12\,\mu F$$

C_1, C_2 and C_3 are in series, so their equivalent capacitance is,

$$\frac{1}{C'} = \frac{1}{12} + \frac{1}{12} + \frac{1}{12}$$

$$= \frac{3}{12}$$

$$C' = \frac{12}{3}$$

$$= 4\,\mu F$$

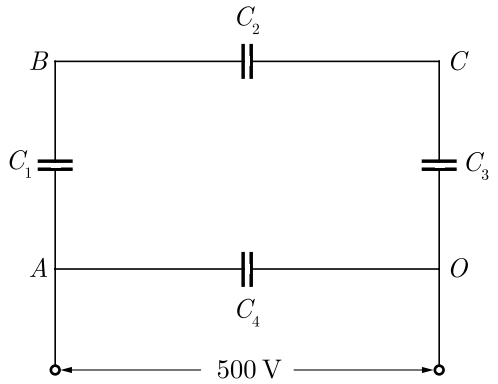
Now C' and C_4 are parallel,so equivalent capacitance is,

$$C = C' + C_4$$

$$= 4 + 12$$

$$= 16\,\mu F$$

162. A network of four capacitors each of $12\,\mu F$ capacitance is connected a 500 V supply as shown in the figure. Determine equivalent capacitance of the network.



Ans : SQP 2013

$$C_1 = C_2 = C_3 = C_4 = 12\,\mu F$$

C_1, C_2 and $C_3 S$ are in series, so their equivalent capacitance is

$$\frac{1}{C'} = \frac{1}{12} + \frac{1}{12} + \frac{1}{12} = \frac{3}{12}$$

$$C' = \frac{12}{3} = 4\,\mu F$$

Now C' and C_4 are parallel, so equivalent capacitance is

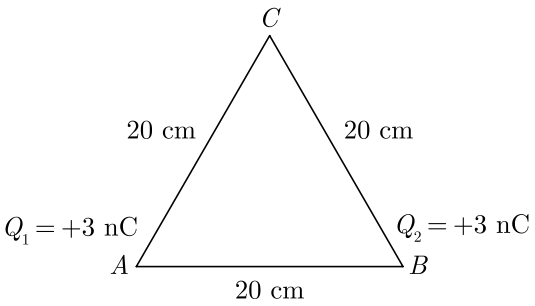
$$C = C' + C_4$$

$$C = 4 + 12 = 16\,\mu F$$

163. The side of an equilateral triangle is 20 cm. Two equal point chargers (+) 3 nC are placed at its two corners. What will be the amount of work done in bringing a (+) 1 nC test charge from infinity to third corner of the triangle.

Ans : Main 2020, 2018

According to the question,we can draw the following diagram,



The amount of work done in bringing a test charge $= +1$ nC from infinity is given by,

$$W = \frac{1}{4\pi\varepsilon_0}\left[\frac{q_1 q_3}{r} + \frac{q_2 q_3}{r}\right]$$

Here, $q_1 = 3\,\text{nC} = 3 \times 10^{-9}\text{C}$

$q_2 = 3\,\text{nC} = 3 \times 10^{-9}\text{C}$

$q_3 = 1\,\text{nC} = 1 \times 10^{-9}\text{C}$

$r = 20\,\text{cm} = 0.2\,\text{m}$

$$W = \frac{1}{4\pi\varepsilon_0}\left[\frac{3 \times 10^{-9} \times 1 \times 10^{-9}}{0.2} + \frac{3 \times 10^{-9} \times 1 \times 10^{-9}}{0.2}\right]$$

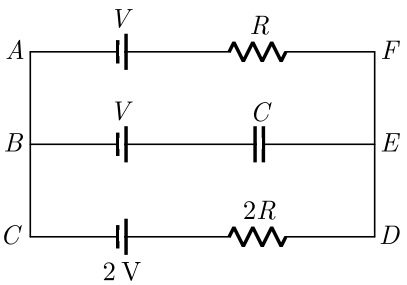
$$= \frac{1}{4\pi\varepsilon_0}[15 \times 10^{-18} + 15 \times 10^{-18}]$$

$$= 9 \times 10^9 \times 30 \times 10^{-18}$$

$$= 2.7 \times 10^{-7}\text{J}$$

164. In the given circuit in the steady state, obtain the expression for :

1. The potential drop
2. The charge
3. The energy stored in the capacitor, C.



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Ans : SQP 2016

1. In steady state, current in the circuit $ACDFA$

$$I = \frac{2V - V}{2R + R} = \frac{V}{3R}$$

Potential at point E, assuming $V_E = 0$

$$V_E = 2V - 2IR$$
$$= 2V - 2R \times \frac{V}{3R} = \frac{4V}{3}$$

Potential difference,

$$V_{BE} = V_E - V$$
$$= \frac{4V}{3} - V = \frac{V}{3}$$

Hence, potential drop across the capacitor is $\frac{V}{3}$.

2. Charge on the capacitor $q = C\left(\frac{V}{3}\right) = \frac{1}{3}CV$.
3. Energy stored in the capacitor,

$$U = \frac{1}{2}C\left(\frac{V}{3}\right)^3 = \frac{1}{18}CV^2$$

165. The capacitance of a parallel plate capacitor is $10\,\mu F$. When distance between its plates is 8 cm. If distance between the plates is reduced to 4 cm, find out the new value capacitance of capacitor ?

Ans : Main 2011

Initial capacitance,

$$C_1 = 10\,\mu F$$

Initial distance between plates,

$$d_1 = 8\text{ cm} = 0.08\text{ m}$$

and final distance between plates,

$$d_2 = 4\text{ cm} = 0.04\text{ m}$$

Capacitance of a parallel plate capacitor,

$$C = \frac{\varepsilon_0 A}{d} \propto \frac{1}{d}$$

Therefore, $\frac{C_1}{C_2} = \frac{d_2}{d_1}$

or $C_2 = \frac{d_1}{d_2} \times C_1$

$$= \frac{0.08}{0.04} \times 10$$
$$= 20\,\mu F$$

where, $C_2 =$ Final capacitance of parallel plate capacitor

166. Three capacitors each of capacitance 9pF are connected in series :

(i) What is the total capacitance of the combination ?

(ii) What is the potential difference across each capacitor if the combination is connected to 120 V supply ?

Ans : Main 2015

(i) Given, $C_1 = C_2 = C_3 = 9\text{ pF}$

When capacitors are connected in series, the equivalent capacitance C_S is given by

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$
$$= \frac{1}{9} + \frac{1}{9} + \frac{1}{9} = \frac{3}{9} = \frac{1}{3}$$

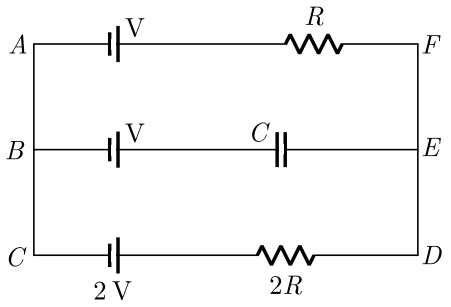
(ii) In series charge on each capacitor remains the same, so charge on each capacitor.

$$q = C_S V$$
$$= (3 \times 10^{-12}\text{ F}) \times (120\text{ V})$$
$$= 3.6 \times 10^{-10}\text{ coulomb}$$

Potential difference across each capacitor,

$$V = \frac{q}{C_1}$$
$$= \frac{3.6 \times 10^{-10}}{9 \times 10^{-12}} = 40\text{ V}$$

167. In the given circuit in the steady state, obtain the expression for (a) the potential drop (b) the charge and (c) the energy stored in the capacitor, C.



Ans : SQP 2015

(a) In steady state, current in the circuit $ACDFA$

$$I = \frac{2V - V}{2R + R} = \frac{V}{3R}$$

Potential at point E,

assuming $V_E = 0$

$$V_E = 2V - 2IR$$
$$= 2V - 2R \times \frac{V}{3R} = \frac{4V}{3}$$

Potential difference,

$$V_{BE} = V_E - V$$
$$= \frac{4V}{3} - V = \frac{V}{3}$$

Hence, potential drop across the capacitor is $\frac{V}{3}$.

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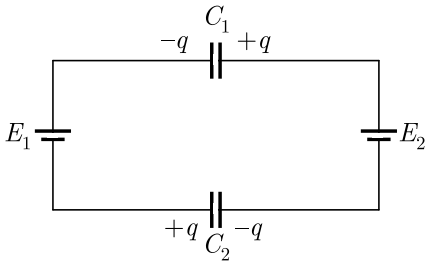
(b) Charge on the capacitor q

$$= C\left(\frac{V}{3}\right) = \frac{1}{3}CV$$

(c) Energy stored in the capacitor

$$U = \frac{1}{2}C\left(\frac{V}{3}\right)^2 = \frac{1}{18}CV^2$$

168. Determine the potential difference across the plates of the capacitor C_1 of the network shown in the figure. [Assume $E_2 > E_1$].



Ans : **Comp 2013, 2011**

Let, $E_2 > E_1$

Therefore, right plate of C_1 has charge $+q$ and left plate of C_1 has charge $-q$. On the same basis, left plate of C_2 has charge $+q$ and right plate of C_2 has charge $-q$.

In closed circuit, potential difference $dV = 0$.

$$\frac{q}{C_1} + E_1 + \frac{q}{C_2} - E_2 = 0$$

$$q\left(\frac{1}{C_1} + \frac{1}{C_2}\right) = E_2 - E_1$$

$$q\left(\frac{C_2 + C_1}{C_1 C_2}\right) = E_2 - E_1$$

$$q = \frac{(E_2 - E_1)\, C_1 C_2}{C_1 + C_2}$$

Hence, potential difference across left and right plate of C_1 is

$$V = \frac{q}{C_1} = \frac{(E_2 - E_1)\, C_2}{C_1 + C_2}$$

169. A parallel plate capacitor has its two plates kept 0.02 m apart. A dielectric slab of thickness 0.01 m is introduced between the plates with its faces parallel to them. The distance between the plates is readjusted to make the capacity of the capacitor $(2/3)^{rd}$ of its original value. Given that the dielectric constant of the slab equals 5, find the new distance between the plates.

Ans : **Main 2014**

Given, $d = 0.02\,\text{m},\ t = 0.01\,\text{m},\ K = 5$

$$C_1 = \frac{C}{5}$$

Using the relation,

$$C = \frac{\varepsilon_0 A}{\left(d - t + \frac{t}{K}\right)} \quad \ldots(1)$$

$$C = \frac{\varepsilon_0 A}{\left(0.02 - 0.01 + \frac{0.01}{5}\right)}$$

$$C = \frac{\varepsilon_0 A}{0.012} \quad \ldots(2)$$

Again, $C_1 = \frac{\varepsilon_0 A}{(d - 0.01 + 0.002)}$

$$\frac{2C}{3} = \frac{\varepsilon_0 A}{(d - 0.01 + 0.002)} \quad \ldots(3)$$

Now dividing equation (3) by equation (2), we get

$$\frac{2\frac{C}{3}}{C} = \frac{\varepsilon_0 A}{(d - 0.01 + 0.002)} \times \frac{0.012}{\varepsilon_0 A}$$

$$2(d - 0.01 + 0.002) = 3 \times 0.012$$

$$2d - 0.02 + 0.004 = 0.036$$

$$2d = 0.036 + 0.02 + 0.004$$

$$2d = 0.052$$

$$d = 0.026\,\text{m}$$

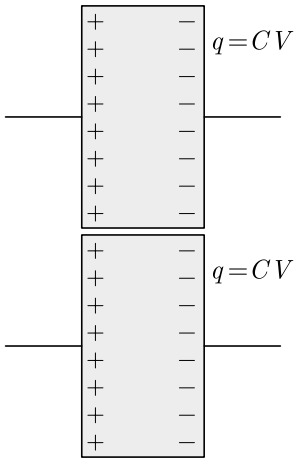
170. A parallel plate capacitor of capacitance C is charged to a potential V. It is then connected to another uncharged capacitor having the same capacitance. Find out the ratio of the energy stored in the combined system to that stored initially in the single capacitor.

Ans : **SQP 2014**

The charge on the capacitor $q = CV$ and initial energy stored in the capacitor.

$$U_1 = \frac{1}{2}\frac{q^2}{C} = \frac{1}{2}CV^2$$

If another uncharged capacitor is connected in series then the same amount of the charge will transfer as shown in figure.



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Keeping charge constant, final voltage $V' = 2\,\text{V}$ and capacitance of combined system $= C_S$.

$$U_f = \frac{1}{2}\frac{q^2}{C} + \frac{1}{2}\frac{q^2}{C} = \frac{q^2}{C}$$

$$U_f : U_i = \frac{q^2}{C} : \frac{q^2}{2C} \quad 2:1$$

Alternately, $U_f : U_i = \frac{1}{2} C_S V'^2 : \frac{1}{2} CV^2$

$$= \frac{1}{2} \times \frac{C}{2} \times (2V)^2 : \frac{1}{2} CV^2$$

$$= CV^2 : \frac{CV^2}{2} = 2:1$$

171. Net capacitance of three identical capacitors in series is $1\,\mu\text{F}$. What will be their net capacitance if connected in parallel ? Find the ratio of energy stored in the two configurations if they are both connected to the same source.

Ans : **Main 2010, 2007**

Let the capacitance of each capacitor is $C\,\mu\text{F}$. Then for series,

$$\frac{1}{C_S} = \frac{1}{C} + \frac{1}{C} + \frac{1}{C}$$

Given, $C_S = 1\,\mu\text{F}$

So, $\frac{1}{1} = \frac{3}{C}$

$$C = 3\,\mu\text{F}$$

Now all three capacitors are arranged in parallel, net capacitance in parallel,

$$C_P = C + C + C$$

$$= 3 + 3 + 3 = 9\,\mu\text{F}$$

Now, energy stored in series combination,

$$E_S s = \frac{1}{2} C_S V^2$$

($V =$ Potential of source)

and energy stored in parallel combination,

$$E_P = \frac{1}{2} C_P V^2$$

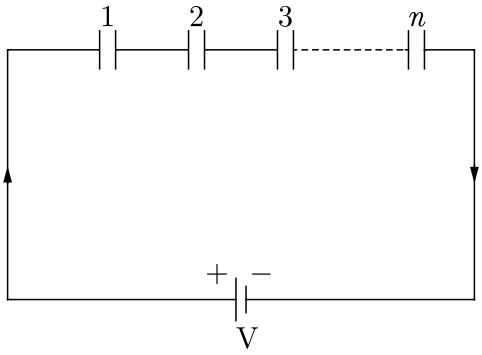
Ratio, $\frac{E_S}{E_P} = \frac{\frac{1}{2} C_S V^2}{\frac{1}{2} C_P V^2} = \frac{C_S}{C_P} = \frac{1}{9}$

Hence, Required ratio is $1:9$.

172. Three capacitors each of capacitance C are connected in series. Their equivalent capacitance is C_s. The same three capacitors are now connected in parallel. Their equivalent capacitance becomes C_p. Find the ratio (C_p/C_s).

Ans : **Main 2011**

Let n capacitors each of capacitance C are connected in series to a battery of voltage V as shown below.



Let C_p and C_s be the equivalent capacitance in parallel and series combination respectively. The equivalent capacitance of the series combination

$$C_s = \frac{C}{n}$$

For the parallel combination,

$$C_p = nC$$

$$= \frac{C_p}{C_s} = \frac{nC}{C/n} = n^2$$

According to the question, $n = 3$

$$\frac{C_p}{C_s} = n^2 = (3)^2 = 9$$

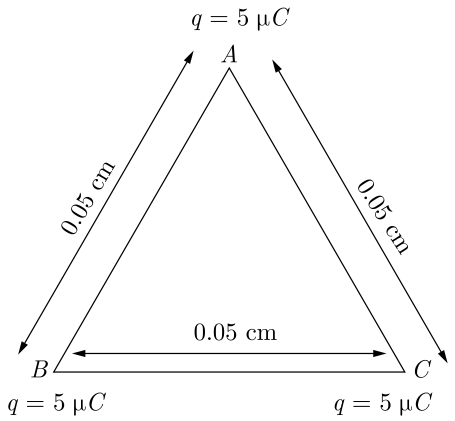
173. Three equal charges of $5.0\,\mu\text{C}$ each are placed at the three vertices of an equilateral triangle of side 5.0 cm each. Calculate the electrostatic potential energy of the system of charges.

Ans : **Main 2007**

Potential energy (PE) of a system of two charges q_1 and q_2 separated by r is

$$U = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{r}$$

For a system of three charges q_1, q_2 and q_3 the total potential energy U is

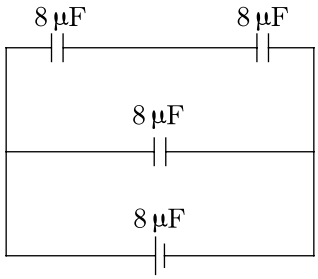


$$U = U_{AB} + U_{BC} + U_{CA}$$
$$= \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1 q_2}{r_{12}} + \frac{q_2 q_3}{r_{23}} + \frac{q_1 q_3}{r_{13}}\right)$$
$$= \frac{1}{4\pi\varepsilon_0} \cdot 3\frac{q^2}{r}$$
$$[r_{12} = r_{23} = r_{13} = r \text{ and } q_1 = q_2 = q_3 = q]$$
$$= 9 \times 10^9 \times \frac{5 \times 10^{-6} \times 5 \times 10^{-6}}{5 \times 10^{-2}} \times 3$$
$$= 13.5 \text{ J}$$

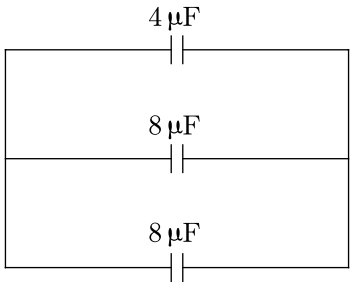
174. You are provided with 8 μF capacitors. Show with the help of a diagram how you will arrange minimum number of them to get a resultant capacitance of 20 μF.

Ans : **Main 2014, 2011**

For getting a capacitance of 20 μF, the combination should be as shown in the diagram.



The series combination of 8 μF capacitors will give equivalent capacitance of 4 μF.



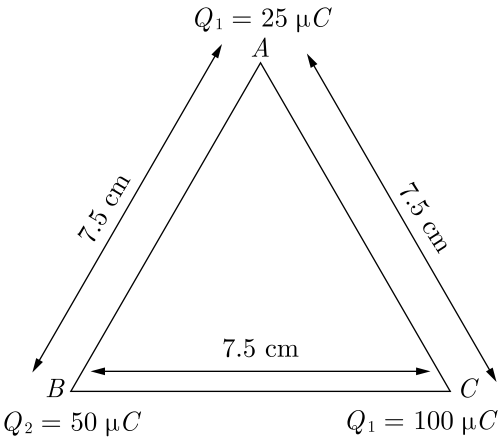
Now, capacitors 4 μF, 8 μF and 8 μF are in parallel.

Hence, $C_{eq} = 4\,\mu\text{F} + 8\,\mu\text{F} + 8\,\mu\text{F}$
$= 20\,\mu\text{F}$

175. Three point charges $Q_1 = 25\,\mu\text{C}$, $Q_2 = 50\,\mu\text{C}$ and $Q_3 = 100\,\mu\text{C}$ are kept at the corners A, B and C respectively of an equilateral ΔABC having each side equal to 7.5 m. Calculate the total electrostatic potential energy of the system.

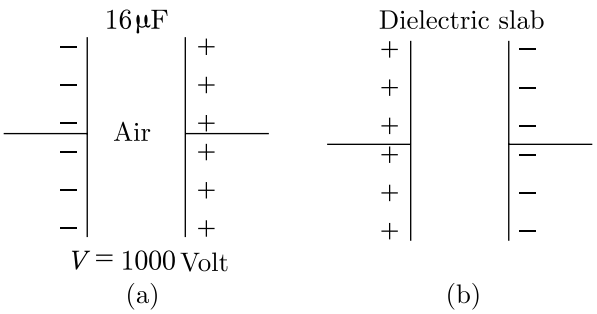
Ans : **Main 2012**

Consider the diagram, total electrostatic potential energy of the system,



$$U = U_{AB} + U_{BC} + U_{CA}$$
$$= \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{AB} + \frac{1}{4\pi\varepsilon_0}\frac{Q_2 Q_3}{BC} + \frac{1}{4\pi\varepsilon_0}\frac{Q_3 Q_1}{CA}$$
$$= \frac{1}{4\pi\varepsilon_0}\left(\frac{Q_1 Q_2}{AB} + \frac{Q_2 Q_3}{BC} + \frac{Q_3 Q_1}{CA}\right)$$
$$= 9 \times 10^9\left(\frac{25 \times 50 \times 10^{-12}}{7.5} + \frac{50 \times 100 \times 10^{-12}}{7.5} + \frac{100 \times 25 \times 10^{-12}}{7.5}\right)$$
$$= \frac{9 \times 10^9 \times 10^{-12}}{7.5} \times 25 \times 50[1 + 4 + 2]$$
$$= \frac{9 \times 2}{15} \times 25 \times 5 \times 7 \times 10^{-2}$$
$$= \frac{21 \times 5}{10} = 10.5 \text{ J}$$

176. An isolated 16 μF parallel plate air capacitor has a potential difference of 1000 V [shown in Fig. (a)]. A dielectric slab having relative permittivity (i.e., dielectric constant) = 5 is introduced to fill the space between the two plates completely [shown in Fig. (b)]. Calculate



(i) the new capacitance of the capacitor.

(ii) the new potential difference between the two plates of the capacitor.

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Ans : **Main 2010, 2007**

Given, $V_0 = 1000$ Volt, $C_0 = 16\,\mu F$

$= 1.6 \times 10^{-5}$ F, $K = 5$

(i) We know that,

$$C_0 = \frac{\varepsilon_0 A}{d}$$

The new capacitance

$$C = KC_0 = 5 \times 1.6 \times 10^{-5}$$

$$= 8 \times 10^{-5}\,\text{F}$$

(ii) New potential

$$V = \frac{V_0}{K} = \frac{1000}{5} = 200 \text{ Volt}$$

177. Three capacitors of capacitance 2 pF, 3 pF and 4 pF are connected in parallel

(i) What is the total capacitance of the combination ?

(ii) Determine the charge on each capacitor if the combination is connected to (a) 100 V supply.

Ans : **Main 2014**

Given, $C_1 = 2\,\text{pF}$, $C_2 = 3\,\text{pF}$, $C_3 = 4\,\text{pF}$

(i) Total capacitance when connected in parallel,

$$C_P = C_1 + C_2 + C_3$$

$$= 2 + 3 + 4 = 9\,\text{pF}$$

(ii) In parallel, the potential difference across each capacitor remains the same, i.e., $V = 100$ Volt

Charge on $C_1 = 2$ pF is

$$q_1 = C_1 V = 2 \times 10^{-12} \times 100$$

$$= 2 \times 10^{-10}\,\text{C}$$

Charge on $C_2 = 3$ pF is

$$q_2 = C_2 V = 3 \times 10^{-12} \times 100$$

$$= 3 \times 10^{-10}\,\text{C}$$

Charge on $C_3 = 4$ pF is

$$q_3 = C_3 V = 4 \times 10^{-12} \times 100$$

$$= 4 \times 10^{-10}\,\text{C}$$

178. You are provided with many identical capacitors each of capacitance 100 μF. How will you connect a minimum number of them to obtain a capacitance of 75 μF ? Draw a diagram in support of your answer.

Ans : **Main SQP 2023**

Given,

Capacitance $= 100\,\mu F$

Capacitors are used to store energy between the plates when current is applied.

When the identical n capacitors are connected in series then net capacitance is, $C_n = C/n$.

If the n identical capacitors are connected in parallel then the net capacitance is, $C_n = nC$.

From the above information, we can construct the circuit connection to obtain a capacitance of $75\,\mu F$.

4 capacitors of capacitance $100\,\mu F$ are connected in the series which has net capacitance, $C_1 = C/4$.

The value of C is $100\,\mu F$.

$$C_s = 100/4$$

$$= 25\,\mu F$$

2 capacitors are connected in series which has net capacitance,

$$C_2 = C/2$$

$$C_2 = 100/2$$

$$= 50\,\mu F$$

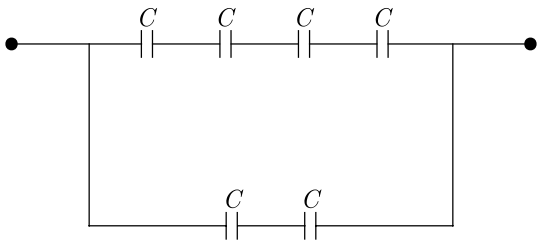
Then, both C_1 and C_2 are connected parallel in the connection.

Now, the net connection is

$$C_n = C_1 + C_2$$

$$C_n = 25 + 50$$

$$= 75\,\mu F$$



$$C = 100\,\mu F$$

179. In a capacitor of capacitor $12\,\mu F$, the distance between the plates is 3 mm. If a dielectric slab of width 2 mm and dielectric constant 2 is inserted between the plates, What will be the new capacitance of capacitor?

Ans : **SQP 2008**

Initial capacitance of capacitor,

$$C_1 = 12\,\mu F = 12 \times 10^{-6}\,\text{F}$$

Distance between plates, $d = 3$ mm

Width of dielectric slab, $t = 2$ mm

Dielectric constant, $K = 2$

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Initial capacitance of the capacitor without dielectric slab,

$$C_1 = \frac{\varepsilon_0 A}{d} = \frac{\varepsilon_0 A}{3}$$

And final capacitance of the capacitor with dielectric slab,

$$C_2 = \frac{\varepsilon_0 A}{(d - t + \frac{t}{K})}$$

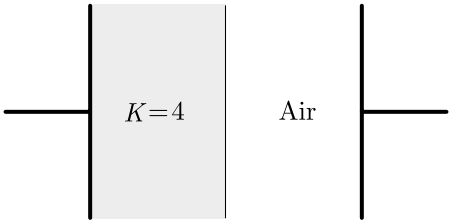
$$= \frac{\varepsilon_0 A}{3 - 2 + \frac{2}{2}} = \frac{\varepsilon_0 A}{2}$$

Therefore, $\frac{C_2}{C_1} = \frac{\frac{\varepsilon_0 A}{2}}{\frac{\varepsilon_0 A}{3}} = \frac{3}{2} = 1.5$

$$C_2 = 12 \times 1.5$$

$$= 18\,\mu F$$

180. Consider a parallel plate capacitor of capacity $10\,\mu F$ with air filled in the gap between the plates. Now one-half of the space between the plates is filled with a dielectric of dielectric constant $K = 4$ as shown in the figure. How much capacitance of capacitor will be changed ?



Ans : **Main 2013**

Initial capacity of the capacitor when filled with air,

$$C = 10\,\mu F$$

and dielectric constant dielectric,

$$K = 4$$

Capacity of the capacitor with half of the space filled with air,

$$C_1 = \frac{C}{2} = \frac{10}{2} = 5\,\mu F$$

And capacity of the capacitor with half of the space filled with dielectric constant,

$$C_2 = KC_1$$

$$= 4 \times 5 = 20\,\mu F$$

Therefore, total capacity of the capacitor,

$$C = C_1 + C_2$$

$$= 5 + 20 = 25\,\mu F$$

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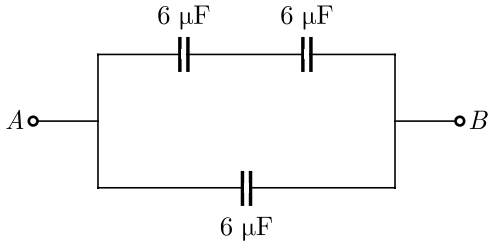
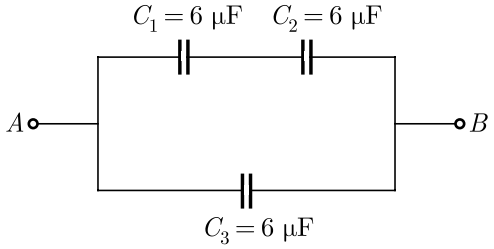
181. What is the equivalent capacity between A and B in the given figure ?



Ans : **Main 2009**



In the circuit C_1 and C_2 are arranged in series combination Hence, Equivalent capacitance,

$$C' = \frac{C_1 \times C_2}{C_1 + C_2}$$

$$= \frac{6 \times 6}{6 + 6}$$

$$= \frac{36}{12} = 3\,\mu F$$

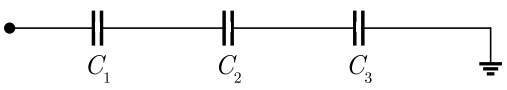
Now C' and C_3 are arranged in parallel combination.

Hence, equivalent capacitance between A and B,

$$C_{eq} = C' + C_3$$

$$= 3 + 6 = 9\,\mu F$$

182. Calculate the potential difference and the energy stored in the capacitor C_2 in the circuit shown in the figure. Given potential at A is 90 V, $C_1 = 20\,\mu F$, $C_2 = 30\,\mu F$, $C_3 = 15\,\mu F$.



Ans : **SQP 2010**

Capacitors C_1, C_2 and C_3 are in series. So, its net capacitance is

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$= \frac{1}{20} + \frac{1}{30} + \frac{1}{15}$$

$$C_S = \frac{20}{3}\,\mu F$$

Net charge on the capacitors, C_1, C_2 and C_3 remain same.

$$q = C_S(V_A - V_E)$$
$$= \frac{20}{3}\,\mu\text{F} \times (90 - 0) = 600\,\mu\text{C}$$

The potential difference across C_2 due to charge $600\,\mu\text{C}$ is

$$V_2 = \frac{q}{C_2} = \frac{600}{30} = 20\text{ V}$$

Energy stored in the capacitor C_2,

$$U_2 = \frac{1}{2}\frac{q^2}{C_2} \qquad \left(\text{or } \frac{1}{2}C_2V_2^2\right)$$
$$= \frac{1}{2} \times 30\,\mu\text{F} \times (20)^2 = 6000\,\mu\text{J}$$
$$= 6 \times 10^{-3}\,\text{J}$$

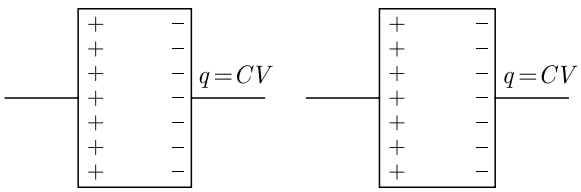
183. A parallel plate capacitor of capacitance C is charged to a potential V. It is then connected to another uncharged capacitor having the same capacitance. Find out the ratio of the energy stored in the combined system to that stored initially in the single capacitor.

Ans : **Main 2009, 2006**

The charge on the capacitor $q = CV$ and initial energy stored in the capacitor

$$U_i = \frac{1}{2}\frac{q^2}{C} = \frac{1}{2}CV^2 \qquad ...(1)$$

If another uncharged capacitor is connected in series then the same amount of the charge will transfer as shown in figure.



Keeping charge constant, final voltage $V' = 2V$ and capacitance of combined system $= C_S$

$$U_f = \frac{1}{2}\frac{q^2}{C} + \frac{1}{2}\frac{q^2}{C} = \frac{q^2}{C} \qquad ...(2)$$

$$U_f : U_i = \frac{q^2}{C} : \frac{q^2}{2C} = 2:1$$

Alternately,

$$U_f : U_i = \frac{1}{2}C_S \cdot V'^2 : \frac{1}{2}CV^2$$
$$= \frac{1}{2} \times \frac{C}{2} \times (2V)^2 : \frac{1}{2}CV^2$$
$$= CV^2 : \frac{CV^2}{2} = 2:1$$

184. Two capacitors $C_1 = 2\,\mu\text{F}$ and $C_2 = 4\,\mu\text{F}$ are connected in series and a potential difference (p.d.) of 1200 V is applied across it. What will be potential difference across 2 μF ?

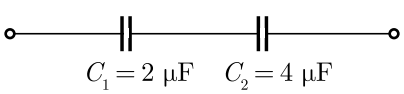
Ans : **SQP 2018, 2015**

Given, $C_1 = 2\mu\text{F} = 2 \times 10^{-6}\text{F}$

$C_2 = 4\mu\text{F} = 4 \times 10^{-6}\text{F}$

Potential difference, $V = 1200$ Volts

The capacitors are connected in series combination as shown in the figure,



Equivalent capacitance,

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$$
$$= \frac{1}{2} + \frac{1}{4} = \frac{2+1}{4}$$
$$C_{eq} = \frac{4}{3}\mu\text{F} = \frac{4}{3} \times 10^{-6}\text{F}$$

Capacitance, $C = \dfrac{Q}{V}$

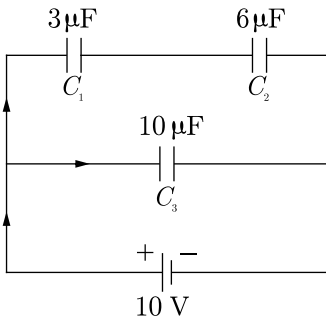
where, $C = C_{eq} = \dfrac{4}{3} \times 10^{-6}\text{F}$

Hence, $Q = C_{eq}V$
$$= \frac{4}{3} \times 10^{-6} \times 1200$$
$$= 1600 \times 10^{-6}\text{C}$$

The Potential difference across $2\,\mu\text{F}$ capacitor is given by,

$$V = \frac{Q}{C} = \frac{1600 \times 10^{-6}}{2 \times 10^{-6}}$$
$$= 800\text{ Volt}$$

185. Three capacitors of capacitance $C_1 = 3\,\mu\text{F}$, $C_2 = 6\,\mu\text{F}$ and $C_3 = 10\,\mu\text{F}$ are connected to a 10 V battery as shown in the figure given below.



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Calculate

(i) equivalent capacitance.

(ii) electrostatic potential energy stored in the system.

Ans : **Main 2019**

(i) C_1 and C_2 are in series combination.
Then, equivalent capacitance,

$$C' = \frac{3 \times 6}{3+6} = 2\,\mu F$$

Now C' and C_3 are in parallel combination.
Then, equivalent capacitance

$$C = C' + C_3 = 2 + 10 = 12\,\mu F$$

(ii) Total charge,

$$Q = CV$$

$$= 12 \times 10 = 120\,\mu C$$

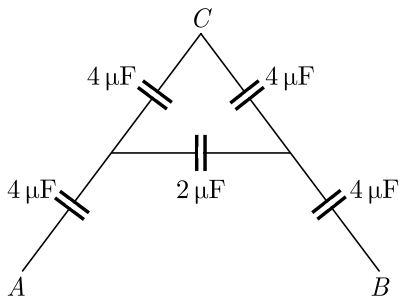
Potential energy stored in the system,

$$U = \frac{1}{2} QV$$

$$= \frac{1}{2} \times 120 \times 10^{-6} \times 10$$

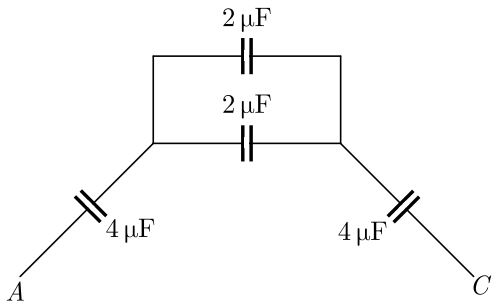
$$= 600 \times 10^{-6} = 6 \times 10^{-4}\,J$$

186. What is the equivalent capacity between points A and B ?



Ans : **Main 2012**

We can reduce the circuit as,



Equivalent capacitance across point C,

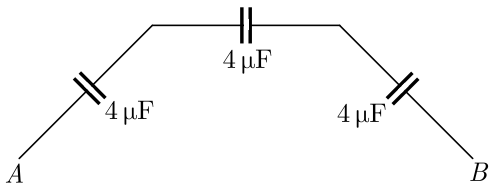
$$\frac{4 \times 4}{4+4} = 2\,\mu F$$

Now $2\,\mu F$ and $2\,\mu F$ are in parallel.

So, equivalent capacitance,

$$2 + 2 = 4\,\mu F$$

Further reduced diagram,

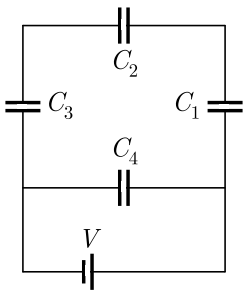


Now all there are in series so equivalent capacitance across A and B would be,

$$\frac{1}{C_{eq}} = \frac{1}{4} + \frac{1}{4} + \frac{1}{4}$$

$$C_{eq} = \frac{4}{3}\,\mu F$$

187. A network of four capacitors of capacity equal to $C_1 = C$, $C_2 = 2C$, $C_3 = 3C$ and $C_4 = 4C$ are connected to a battery as shown in the figure. What is the ratio of the charges on C_2 and C_4 ?



Ans : **SQP 2005**

Capacitances, $C_1 = C$, $C_2 = 2C$

$C_3 = 3C$, $C_4 = 4C$

And Voltage of battery $= V$.

the capacitors C_1, C_2 and C_3 are in series combination.

Therefore relation for their effective capacitance C_S is,

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$= \frac{1}{C} + \frac{1}{2C} + \frac{1}{3C}$$

$$= \frac{6+3+2}{6C} = \frac{11}{6C}$$

or $$C_S = \frac{6C}{11}$$

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We also know that as C_1, C_2 and C_3 are in series, therefore charge on each capacitor is same.

Therefore charge on C_2 capacitor,

$$q = C_S V = \frac{6CV}{11} \quad ...(1)$$

Similarly, charge on C_4 capacitor,

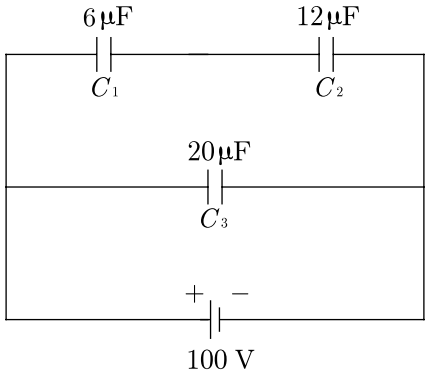
$$q' = C_4 V = 4CV \quad ...(2)$$

Dividing equation (1) by (2),

$$\frac{q}{q'} = \frac{6CV/11}{4CV}$$

$$= \frac{6}{44} = \frac{3}{22}$$

188. Three capacitors $C_1 = 6\,\mu F$, $C_2 = 12\,\mu F$ and $C_3 = 20\,\mu F$ are connected to a 100 V battery as shown in figure below.



Calculate

(i) charge on each plate of capacitor C_1.

(ii) electrostatic potential energy stored in capacitor C_3.

Ans : Main 2013, 2011

We have to apply the concept of series and parallel combination to find equivalent capacitance.

(i) It is clear from the diagram that C_1 and C_2 are in series.

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{6} + \frac{1}{12}$$

$$= \frac{2+1}{12} = \frac{3}{12} = \frac{1}{4}$$

$$C_{eq} = 4\,\mu F$$

Charge on $4\,\mu F$ capacitor,

$$q = CV = 4 \times 10^{-6} \times 100$$

$$= 4 \times 10^{-4}\,C$$

Charge on positive plate of C_1 is $+4 \times 10^{-4}\,C$ and on negative plate of C_1 is $-4 \times 10^{-4}\,C$. Note that charge on C_1 and C_2 will be same.

(ii) Electric potential difference across the plate of C_3 capacitor = 100 V

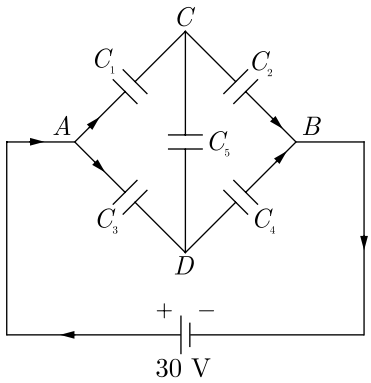
Electrostatic energy,

$$= \frac{1}{2} CV^2$$

$$= \frac{1}{2} \times 20 \times 10^{-6} \times 100 \times 100$$

$$= 10^{-1} = 0.1\,J$$

189. Find the equivalent capacitance of the following circuit between the junctions A and B given $C_1 = C_2 = C_3 = C_4 = 10\,\mu F$ and $C_5 = 5\,\mu F$.



Ans : Main 2008

For a Wheatstone bridge to be balanced, the ratio of capacitances of adjacent arms must be equal.

Clearly, from the given circuit

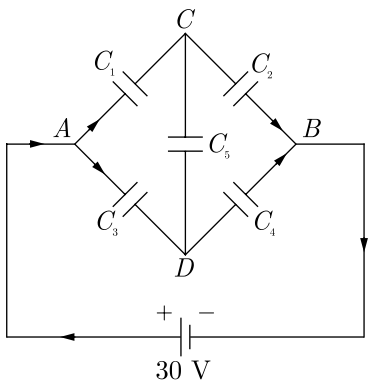
$$C_1 C_4 = 100\,\mu F \text{ and } C_3 C_2 = 100\,\mu F$$

$$C_1 C_4 = C_2 C_3$$

$$\frac{C_1}{C_2} = \frac{C_3}{C_4}$$

So, it is a balanced Wheatstone bridge.

Now, we can remove C_5 from the given circuit.



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So, C_1 and C_2 are in series,

$$\frac{1}{C'} = \frac{1}{10} + \frac{1}{10} = \frac{1}{5}$$

$$C' = 5\,\mu F$$

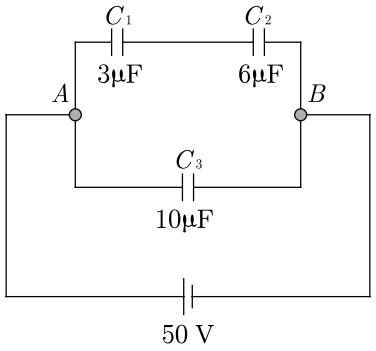
and C_3 and C_4 are in series, $C'' = 5\,\mu F$

Now, C' and C'' are in parallel,

Net capacitance,

$$C = C' + C'' = 5 + 5 = 10\,\mu F$$

190. Three capacitors $C_1 = 3\,\mu F$, $C_2 = 6\,\mu F$ and $C_3 = 10\,\mu F$ are connected to a 50 V battery as shown in the figure below.



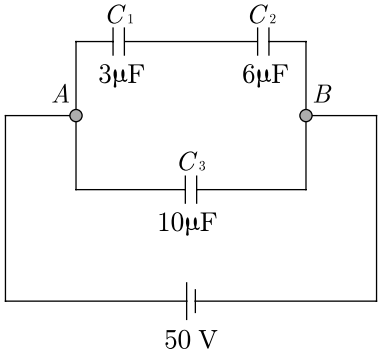
Calculate

(i) the equivalent capacitance of the circuit between points A and B.

(ii) the charge on C_1.

Ans : SQP 2017, 2014

(i)



From the above figure, as C_1 and C_2 are connected in series,

Hence, $$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$\frac{1}{C_{eq}} = \frac{1}{3} + \frac{1}{6}$$

$$C_{eq} = 2\,\mu F$$

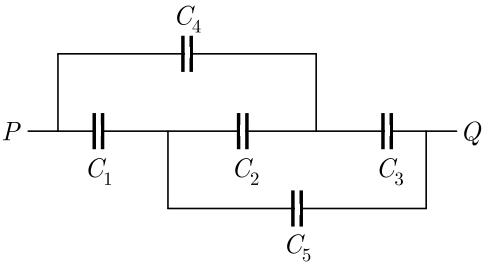
Now, C_{eq} is in parallel with C_3, hence equivalent capacitance of the circuit between points A and B will be $10 + 2 = 12\,\mu F$

(ii) Capacitors C_1 and C_2 are in series. Thus, charge on equivalent capacitance of C_1 and C_2 will be same as individual charge on C_1 and C_2.

Charge on C_1 $= q_1 = (C_{eq})(V)$

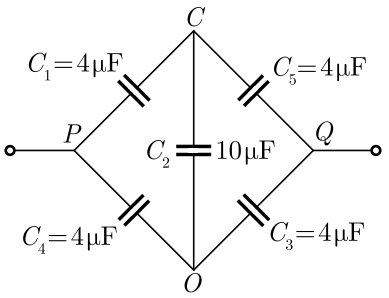
$= (2\,\mu F)(50\text{ V}) = 100\,\mu C$

191. In the given figure, find the capacitance resistance between P and Q. If C_1, C_3, C_4 and C_5 are each of $4\,\mu F$ and $C_2 = 10\,\mu F$.



Ans : Comp 2019

The equivalent circuit of given circuit is drawer below,



The above circuit is formed a balanced Wheatstone bridge. Because,

$$\frac{C_1}{C_5} = \frac{C_4}{C_3}$$

Hence, C_2 is ineffective.

In the circuit C_1 and C_5 in series combination.

$$C_{PCQ} = \frac{C_1 \times C_5}{C_1 + C_5}$$

$$= \frac{4 \times 4}{4 + 4} = 2\,\mu F$$

Similarly, $$C_{POQ} = \frac{C_3 \times C_4}{C_3 + C_4}$$

$$= \frac{4 \times 4}{4 + 4} = 2\,\mu F$$

C_{PCQ} and C_{POQ} are arranged in parallel combination.

Hence, $$C_{eq} = C_{PCQ} + C_{POQ} = 2 + 2 = 4\,\mu F$$

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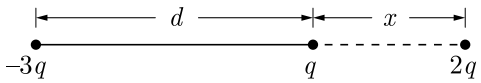
192. Two charges q and $-3q$ are placed on X-axis at a separation d. Where should a third charge $2q$ be placed such that it will not experience any force ? Also calculate potential energy of the system.

Ans : **Main 2016, 2015**

According to the question,



The forces need to be balanced so that the force that $2q$ experiences is cancelled out. So assuming on the line joining q and $-3q$, $-2q$ is x distance from q.

$$\frac{k(q)(2q)}{x^2} = \frac{4}{4\pi\varepsilon_0}\frac{(3q)(2q)}{(x+d)^2}$$

$$\frac{1}{x^2} = \frac{3}{(x+d)^2}$$

$$x^2 + d^2 + 2xd = 3x^2$$

$$2x^2 - 2xd - d^2 = 0$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$= \frac{2d \pm \sqrt{4d^2 + 8d^2}}{2 \times 2}$$

$$x = \frac{2d \pm 2\sqrt{3} - d}{2 \times 2}$$

$$= \frac{d(1 \pm \sqrt{3})}{2}$$

Potential energy of the system is given by,

$$V = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1 q_2}{r_{12}} + \frac{q_2 q_3}{r_{23}} + \frac{q_3 q_1}{r_{31}}\right)$$

$$= \frac{1}{4\pi\varepsilon_0}\left[\frac{2q^3}{\left(\frac{1+\sqrt{3}}{2}\right)d} - \frac{3d^2}{d} - \frac{6q^2}{\left(\frac{3+\sqrt{3}}{2}\right)d}\right]$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{q^2}{d}\left(\frac{4}{1+\sqrt{3}} - \frac{3}{1} - \frac{12}{3+\sqrt{3}}\right)$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{q^2}{d}\left(\frac{4}{1+\sqrt{3}} - \frac{3}{1} - \frac{4\sqrt{3}}{\sqrt{3}+1}\right)$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{q^2}{a}\left(\frac{4-3\sqrt{3}-3-4\sqrt{3}}{\sqrt{3}+1}\right)$$

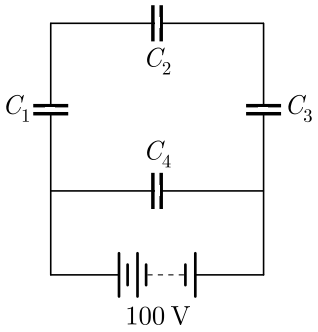
$$= \frac{1}{4\pi\varepsilon_0}\frac{q^2}{d}\left(\frac{1-7\sqrt{3}}{\sqrt{3}+1} \times \frac{\sqrt{3}-1}{\sqrt{3}-1}\right)$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{q^2}{d}\left(\frac{\sqrt{3}-21-1+7\sqrt{3}}{2}\right)$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{q^2}{d}\left(\frac{8\sqrt{3}-22}{2}\right)$$

$$= -\frac{1}{4\pi\varepsilon_0}\frac{q^2}{d}(11 - 4\sqrt{3})$$

193. A network of four capacitors, each of capacitance 15μF, is connected across a battery of 100 V, as shown in the figure. Find the net capacitance and the charge on the capacitor C_4.



Ans : **Main 2019**

In the given network, C_1, C_2 and C_3 are connected in series, the net capacitance of this series is,

$$\frac{1}{C'} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

As, $C_1 = C_2 = C_3 = C_4 = 15\mu F$

Hence, $\frac{1}{C'} = \frac{1}{15} + \frac{1}{15} + \frac{1}{15} = \frac{3}{15} = \frac{1}{15}$

Hence, $C' = 15\mu F$

Now, C' and C_4 are connected in parallel. So total capacitance of combination

$$= C' + C_4$$

$$= 5 + 15 = 20\mu F$$

For capacitor C_4, the net charge is Q (say), then

$$\frac{Q}{C_4} = 100 \text{ V}$$

$$Q = C_4 \times 100$$

$$= 15 \times 10^{-6} \times 100$$

$$= 1.5 \times 10^{-3} \text{ C}$$

194. Two capacitors of unknown capacitances C_1 and C_2 are connected first in series and then in parallel across a battery of 100 V. If the energy stored in the two combination is 0.045 J and 0.25 J respectively, determine the value of C_1 and C_2. Also calculate the charge on each capacitor in parallel combination.

Ans : **Main 2008**

Energy stored in a capacitor,

$$E = \frac{1}{2}CV^2$$

In parallel, $0.25 = \frac{1}{2}(C_1 + C_2)(100)^2$ ...(1)

In series, $0.045 = \frac{1}{2}\left(\frac{C_1 C_2}{C_1 + C_2}\right)(100)^2$ ...(2)

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From equation (1),

$$C_1 + C_2 = 0.25 \times 2 \times 10^{-4}$$

$$C_1 + C_2 = 5 \times 10^{-5} \quad ...(3)$$

From equation (2),

$$\frac{C_1 C_2}{C_1 + C_2} = 0.45 \times 2 \times 10^{-4} \quad ...(4)$$

$$\frac{C_1 C_2}{C_1 + C_2} = 0.09 \times 10^{-4} = 9 \times 10^{-6}$$

From equation (4),

$$C_1 C_2 = \frac{2 \times 0.045 \times 5 \times 10^{-5}}{10^4}$$

$$= 4.5 \times 10^{-10}$$

$$C_1 - C_2 = \sqrt{(C_1 + C_2)^2 - 4 C_1 C_2}$$

$$C_1 - C_2 = 2.64 \times 10^{-5} \quad ...(5)$$

Solving equation (3) and (5),

$$C_1 = 38.2\,\mu F$$

$$C_2 = 11.8\,\mu F$$

In parallel, $Q_1 = C_1 V = 38.2 \times 10^{-6} \times 100$

$$= 38.2 \times 10^{-4}\,C$$

and $Q_2 = C_2 V = 11.8 \times 10^{-6} \times 100$

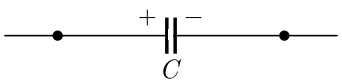
$$= 11.8 \times 10^{-4}\,C$$

195. A capacitor of unknown capacitance is connected across a battery of V volts. The charge stored in it is $360\,\mu C$. When potential across the capacitor is reduced by 120 V, the charge stored in it becomes $120\,\mu C$.

Calculate:

1. The potential V and the unknown capacitance C.
2. What will be the charge stored in the capacitor, if the voltage applied had increased by 120 V?

Ans : **Main 2009, 2007**



1. If unknown capacitor of capacitance C is connected to a battery of V bolts,

$$Q = CV$$

$$CV = 360\,\mu C \quad ...(1)$$

On reducing the potential/voltage by 120 V.

So, $Q' = C(V - 120)$

$$C(V - 120) = 120\,\mu C \quad ...(2)$$

On solving equation (1) and (2)

$$\frac{360\,\mu C}{V} = \frac{120\,\mu C}{V - 120}$$

$$V = 180 \text{ Volt}$$

Unknown capacitance from equation (1),

$$Q = CV$$

$$360\,\mu C = C \times 180\ V$$

$$C = \frac{360\,\mu C}{180\ V} = 2$$

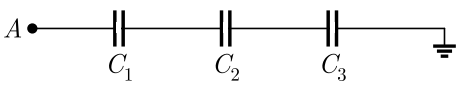
$$C = 2\,\mu F$$

2. Charge on the capacitor, if voltage is increased by 120 V.

$$Q = C(V + 120)$$

$$= 2(180 + 120) = 600\,\mu C$$

196. Calculate the potential difference and the energy stored in the capacitor C_2 in the circuit shown in the figure. Given potential at A is 90 V, $C_1 = 20\,\mu F$, $C_2 = 30\,\mu F$, $C_3 = 15\,\mu F$.



Ans : **Comp 2007**

Capacitors C_1, C_2 and C_3 are in series. So its net capacitance is,

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$= \frac{1}{20} + \frac{1}{30} + \frac{1}{15}$$

$$C_S = \frac{20}{3}\,\mu F$$

Net charge on the capacitors C_1, C_2 and C_3 remain same.

$$q = C_S(V_A - V_E)$$

$$= \frac{20}{3}\,\mu F \times (90 - 0) = 600\,\mu C$$

The potential difference across C_2 due to charge $600\,\mu C$ is,

$$V_2 = \frac{q}{C_2}$$

$$= \frac{600}{30} = 20 \text{ Volt}$$

Energy stored in the capacitor C_2

$$U_2 = \frac{1}{2}\frac{q^2}{C_2} \text{ or } \frac{1}{2} C_2 V_2^2$$

$$= \frac{1}{2} \times 30\,\mu F \times (20)^2$$

$$= 6000\,\mu J = 6 \times 10^{-3}\,J$$

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197. In a parallel plate capacitor with air between the plates, each plate has an area of $6 \times 10^{-3}\,m^2$ and the separation between the plate is 3 mm.

1. Calculate the capacitance of the capacitor.
2. If this capacitor is connected to 100 V supply, what would bet he change on each plate?
3. How would charge on the plates be affected if a 3 mm thick mica sheet of $K = 6$ is inserted between the plates while the voltage supply remains connected?

Ans : **Main 2016, 2014**

Area of each plate,

$$A = 6 \times 10^{-3}\,m^2$$

Distance between plates,

$$d = 3\,mm = 3 \times 10^{3}\,m$$

1. Capacitance of parallel plate capacitor is given by,

$$C = \frac{\varepsilon_0 A}{d}$$

$$\varepsilon_0 = 8.85 \times 10^{-12}$$

$$C = \frac{8.85 \times 10^{-12} \times 6 \times 10^{-3}}{3 \times 10^{-3}}$$

$$C = 1.77 \times 10^{-11}\,F$$

2. Charge on parallel plate capacitor is given by

$$Q = CV$$

Given, $V = 100$ Volt

Now, $Q = 17.7 \times 10^{-12} \times 100$

$$Q = 1 \times 10^{-10}\,C \qquad ...(1)$$

3. Given,

$$K = 6$$

Now, $C' = KC$

$Q' = KQ$ [From equation (1)]

$$= 6 \times 1.77 \times 10^{-10}$$

$$= 10.62 \times 10^{-10}\,C$$

198. et capacitance of three identical capacitors in series is $1\,\mu F$. What will be their net capacitance if connected in parallel ?

Find the ratio of energy stored in the two configurations if they are both connected to the same source.

Ans : **Main 2007**

Let the capacitance of each capacitor is $C\,\mu F$. Then for series,

$$\frac{1}{C_S} = \frac{1}{C} + \frac{1}{C} + \frac{1}{C}$$

Given, $C_S = 1\,\mu F$

So, $\frac{1}{1} = \frac{3}{C}$

$$C = 3\,\mu F$$

Now all three capacitors are arranged in parallel, net capacitance in parallel,

$$C_P = C + C + C$$

$$= 3 + 3 + 3 = 9\,\mu F$$

Now, energy stored in series combination,

$$E_S = \frac{1}{2} C_S V^2$$

(V = potential of source)

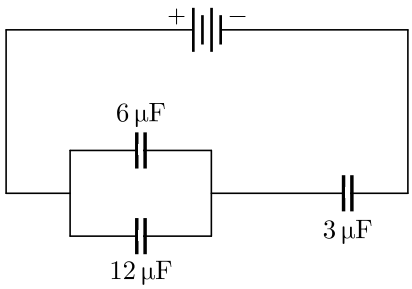
and energy stored in parallel combination,

$$E_P = \frac{1}{2} C_P V^2$$

Ratio, $\frac{E_S}{E_P} = \frac{\frac{1}{2} C_S V^2}{\frac{1}{2} C_P V^2} = \frac{C_S}{C_P} = \frac{1}{9}$

Required ratio = 1 : 9

199. In the following arrangement of capacitors, the energy stored in $6\,\mu F$ capacitor is E. Find the value of the following.



1. Energy stored in $12\,\mu F$ capacitor.
2. Energy stored in $3\,\mu F$ capacitor.
3. Total energy drawn from the battery.

Ans : **Main 2012**

The energy stored in $6\,\mu F$ capacitor.

1. Let V be the voltage across $6\,\mu F$ is E.
   Also $6\,\mu F$ and $12\,\mu F$ capacitors are in parallel.
   Therefore,
   Voltage across $12\,\mu F$

   = Voltage across $6\,\mu F$ capacitor

$$E = \frac{1}{2} CV^2 = \frac{1}{2} \times 6 \times V^2$$

$$V = \sqrt{\frac{E}{3}} \qquad \text{(Energy stored in } 12\,\mu F\text{)}$$

$$= \frac{1}{2} \times 12 \left(\sqrt{\frac{E}{3}}\right)^2 = 2E$$

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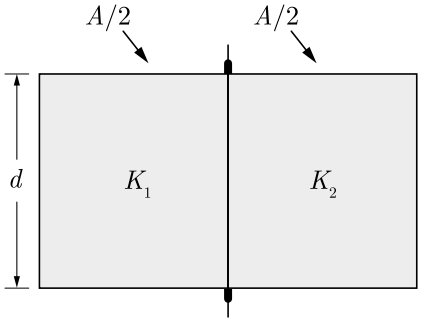
2. Since charge remains constant in series. Sum of charge on 6 μF capacitor and 12 μF capacitor is equal to charge on 3 μF capacitor (Using $Q = CV$).
Charge on 3 μF capacitor,

$$E = \frac{Q^2}{2C} = \frac{(18\,V)^2}{2 \times 3}$$
$$= \frac{18 \times 18}{6}\left(\frac{\sqrt{E}}{3}\right)^2 = 18\,E$$

3. Total energy drawn from battery
$$= E + 2E + 18E$$
$$= 21E$$

200. Two materials of dielectric constant K_1 and K_2 are filled between two parallel plates of a capacitor as shown in figure. Find out the net capacity of the capacitor?



A = Area of plates

Ans : SQP 2012

Dielectric constant of first material $= K_1$

Dielectric constant of second material $= K_2$

capacity of the first capacitor,

$$C_1 = \frac{K_1\varepsilon_0\left(\frac{A}{2}\right)}{d}$$
$$= \frac{K_1\varepsilon_0 A}{2d}$$

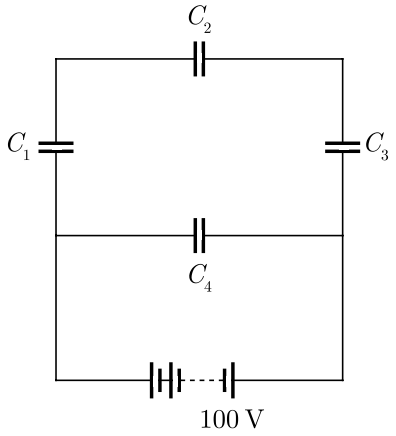
Similarly, capacity of the second capacitor,

$$C_2 = \frac{\varepsilon_0 K_2 A}{2d}$$

Since, the two capacitors are connected in a parallel combination,
Therefore their net capacity of the capacitor,

$$C = C_1 + C_2$$
$$= \frac{\varepsilon_0 K_1 A}{2d} + \frac{\varepsilon_0 K_2 A}{2d}$$
$$= \frac{A\varepsilon_0(K_1 + K_2)}{2d}$$

201. A network of four capacitors, each of capacitance 15 μF is connected across a battery of 100 V, as shown in the figure. Find the net capacitance and the charge on the capacitor C_4.



Ans : Main 2006

In the given network, C_1, C_2 and C_3 are connected in series, the net capacitance of this series is

$$\frac{1}{C'} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

As, $C_1 = C_2 = C_3 = C_4 = 15\,\mu F$

Hence, $\frac{1}{C'} = \frac{1}{15} + \frac{1}{15} + \frac{1}{15} = \frac{3}{15} = \frac{1}{15}$

Hence, $C' = 5\,\mu F$

Now C' and C_4 are connected in parallel, so total capacitance of combination

$$= C' + C_4 = 5 + 15 = 20\,\mu F$$

For capacitor C_4, the net charge is Q (say), then

$$\frac{Q}{C_4} = 100\ V$$

or $Q = C_4 \times 100$
$$= 15 \times 10^{-6} \times 100$$
$$= 1.5 \times 10^{-3}\ C$$

202. A capacitor of unknown capacitance is connected across a battery of V volts. The charge stored in it is 360 μC. When potential across the capacitor is reduced by 120 V, the charge stored in it becomes 120 μC.
Calculate :
(i) The potential V and the unknown capacitance C.
(ii) What will be the charge stored in the capacitor, if the voltage applied had increased by 120 V ?

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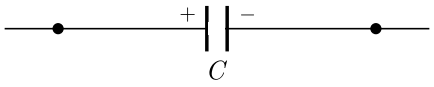
Ans : SQP 2013



(i) If unknown capacitor of capacitance C is connected to a battery of V volts,

$$Q = CV$$

$$CV = 360\,\mu C \quad ...(1)$$

On reducing the potential/voltage by 120 Volt

So, $$Q' = C(V-120)$$

$$C(V-120) = 120\,\mu C \quad ...(2)$$

On solving equation (1) and (2),

$$\frac{360\,\mu C}{V} = \frac{120\,\mu C}{V-120}$$

$$V = 180 \text{ Volt}$$

Unknown capacitance from equation (1),

$$Q = CV$$

$$360\,\mu C = C \times 180\ V$$

$$C = \frac{360\,\mu C}{180\ V} = 2$$

$$C = 2\,\mu F$$

(ii) Charge on the capacitor, if voltage is increased by 120 Volt,

$$Q = C(V+120)$$

$$= 2(180+120)$$

$$= 600\,\mu C$$

203. A $4\,\mu F$ capacitor is charged by a 200 V supply. It is then disconnected from the supply and is connected to another uncharged $2\,\mu F$ capacitor. How much electrostatic energy of the first capacitor is lost in the form of heat and electromagnetic radiation ?

Ans : Main 2015, 2010

Given, $C_1 = 4\,\mu F = 4 \times 10^{-6}$

$V_1 = 200$ Volt

$C_2 = 2\,\mu F = 2 \times 10^{-6}\,F$

Initial energy of first capacitor,

$$U_1 = \frac{1}{2} C_1 V_1^2$$

$$= \frac{1}{2} \times (4 \times 10^{-6}) \times (200)^2$$

$$= 8 \times 10^{-2}\,J$$

When another uncharged capacitor $C_2 = 2\,\mu F$, is connected across capacitor C_1 then common potential difference

$$V = \frac{q_1+q_2}{C_1+C_2} = \frac{C_1V_1+0}{C_1+C_2}$$

$$= \frac{4 \times 10^{-6} \times 200}{(4+2) \times 10^{-6}} = \frac{400}{3} \text{ volt}$$

Final electrostatic energy,

$$U_2 = \frac{1}{2}(C_1+C_2)\,V^2$$

$$= \frac{1}{2} \times (4 \times 2) \times 10^{-6} \times \left(\frac{400}{3}\right)^2$$

$$= \frac{16}{3} \times 10^{-2}\,J = 5.33 \times 10^{-2}\,J$$

Energy loss,

$$\Delta U = U_1 - U_2$$

$$= 8 \times 10^{-2} - 5.33 \times 10^{-2}$$

$$= 2.67 \times 10^{-2}\,J$$

204. Two capacitor of unknown capacitances C_1 and C_2 are connected first in series and then in parallel across a battery of 100 V. If the energy stored in the two combinations is 0.045 J and 0.25 J respectively, determine the value of C_1 and C_2. Also calculate the charge on each capacitor in parallel combination.

Ans : Comp 2005

Energy stored in a capacitor,

$$E = \frac{1}{2} CV^2$$

In parallel, $$0.25 = \frac{1}{2}(C_1+C_2)(100)^2 \quad ...(1)$$

In series, $$0.045 = \frac{1}{2}\left(\frac{C_1C_2}{C_1+C_2}\right)(100)^2 \quad ...(2)$$

From (1), $$C_1+C_2 = 0.25 \times 2 \times 10^{-4}$$

$$C_1+C_2 = 5 \times 10^{-5} \quad ...(3)$$

From (2), $$\frac{C_1C_2}{C_1+C_2} = 0.45 \times 2 \times 10^{-4} \quad ...(4)$$

$$\frac{C_1C_2}{C_1+C_2} = 0.09 \times 10^{-4} = 9 \times 10^{-6}$$

From (4), $$C_1+C_2 = \frac{2 \times 0.045 \times 5 \times 10^{-5}}{10^4}$$

$$= 4.5 \times 10^{-10}$$

$$C_1+C_2 = \sqrt{(C_1+C_2)^2 - 4C_1C_2}$$

$$C_1+C_2 = 2.64 \times 10^{-5} \quad ...(5)$$

Solving (3) and (5),

$$C_1 = 38.2\,\mu F$$

$$C_2 = 11.8\,\mu F$$

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In parallel, $Q_1 = C_1 V = 38.2 \times 10^{-6} \times 100$

$= 38.2 \times 10^{-4}\,\text{C}$

$Q_2 = C_2 V = 11.8 \times 10^{-6} \times 100$

$= 11.8 \times 10^{-4}\,\text{C}$

205. In a parallel plate capacitor with air between the plates, each plate has an area of $6 \times 10^{-3}\,\text{m}^2$ and the separation between the plate is 3 mm.

(i) Calculate the capacitance of the capacitor.

(ii) If this capacitor is connected to 100 V supply, what would be the change on each plate ?

(ii) How would charge on the plates be affected if a 3 mm thick mica sheet of $K = 6$ is inserted between the plates while the voltage supply remains connected ?

Ans : **Main 2008**

Area of each plate,

$$A = 6 \times 10^{-3}\,\text{m}^2$$

Distance between plates,

$$d = 3\,\text{mm} = 3 \times 10^{-3}\,\text{m}$$

(i) Capacitance of parallel plate capacitor is given by

$$C = \frac{\varepsilon_0 A}{d}$$

$$C = \frac{8.85 \times 10^{-12} \times 6 \times 10^{-3}}{3 \times 10^{-3}}$$

$$C = 1.77 \times 10^{-11}\,\text{F}$$

(ii) Charge on parallel plate capacitor is given by

$$Q = CV$$

Given, $V = 100$ Volt

Now, $Q = 1.77 \times 10^{-12} \times 100$

$Q = 1.77 \times 10^{-10}\,\text{C}$ ...(1)

(iii) Given, $K = 6$

Now, $C' = KC$

$Q' = KQ$ [From Equation (1)]

$Q' = 6 \times 1.77 \times 10^{-10}$

$Q' = 10.62 \times 10^{-10}\,\text{C}$

206. The two plates of a parallel plate capacitor are 5 mm apart. A slab of a dielectric of thickness 4 mm is introduced between the plates with its faces parallel to them. The distance between the plates is adjusted so that the capacitance of the capacitor becomes equal to its original value. If the new distance between the plates equals 8 mm, what is the dielectric constant of the dielectric used ?

Ans : **Main 2006, 2005**

Let original capacitance

$$C_0 = \frac{\varepsilon_0 A}{d}$$

Here, $d = 5\,\text{mm}$

$= 5 \times 10^{-3}\,\text{m}$

So, $\varepsilon_0 A = 5 \times 10^{-3} C_0$

Now, $d = 8\,\text{mm} = 8 \times 10^{-3}\,\text{m}$

$t = 4\,\text{mm} = 4 \times 10^{-3}$

and $C = C_0$

So, $C = \frac{\varepsilon_0 A}{d - t(1 - \frac{1}{K})}$

where $K =$ dielectric constant

Hence, $C_0 = \frac{5 \times 10^{-3} \times C_0}{d - t\left[1 - \frac{1}{K}\right]}$

or $d - t\left(1 - \frac{1}{K}\right) = 5 \times 10^{-3}$

$8 \times 10^{-3} - 5 \times 10^{-3} = t\left(1 - \frac{1}{K}\right)$

$t\left(1 - \frac{1}{K}\right)S = 3 \times 10^{-3}$

$\left(1 - \frac{1}{K}\right) = \frac{3 \times 10^{-3}}{4 \times 10^{-3}} s$

$1 - \frac{1}{K} = 0.75$

$\frac{1}{K} = 0.25$

$K = 4$

So, dielectric constant $= 4$

207. A capacitor of 200 pF is charged by a 300 V battery. The battery is then disconnected and the charged capacitor is connected to another uncharged capacitor of 100 pF. Calculate the difference between the final energy stored in the combined system and the initial energy stored in the single capacitor.

Ans : **Main 2018**

Given,

$$C = 200\,\text{pF} = 200 \times 10^{-12}\,\text{F}$$

$$V = 300\,\text{Volt}$$

The energy (initially) stored by the capacitor is,

$$U_i = \frac{1}{2} CV^2$$

$$= \frac{1}{2} \times 200 \times 10^{-12} \times 300 \times 300$$

$$= 9 \times 10^{-6}\,\text{J}$$

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The charge on the capacitor when charge through 300V battery is,

$$Q = CV = 200 \times 10^{-12} \times 300$$
$$= 6 \times 10^{-8}\,\text{C}$$

When two capacitor are connected, they have their positive plates and negative plates at the same potential. Let V be the common potential difference. By charge conservation, charge would distribute but total charge would remain constant.

Thus, $Q = q + q'$

$$\frac{q}{C} = \frac{q'}{C'}$$
$$\frac{q}{200} = \frac{q'}{100}$$
$$q = 2q'\,sd$$

Thus, $Q = 2q' + q' = 3q'$

So, $q' = \frac{Q}{3} = \frac{60\,\text{nC}}{3} = 20\,\text{nC}$

and $q = 2q' = 40\,\text{nC}$

Thus, final energy,

$$U_f = \frac{q^2}{2C} + \frac{q'^2}{2C'}$$
$$= \frac{1}{2} \times \frac{(40 \times 10^{-9})^2}{200 \times 10^{-12}} + \frac{1}{2} \times \frac{(20 \times 10^{-9})^2}{100 \times 10^{-12}}$$
$$= 4 \times 10^{-6} + 2 \times 10^{-6}$$
$$= 6 \times 10^{-6}\,\text{J}$$

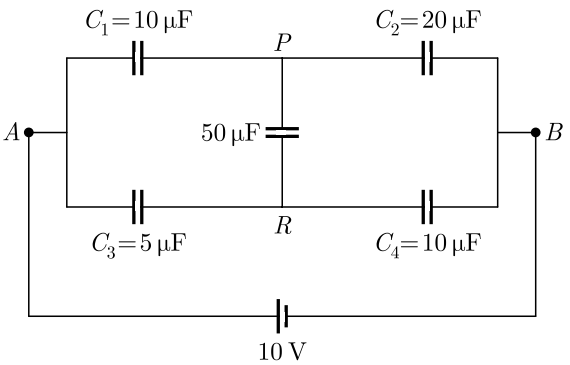
Difference in energy

= Final energy − Initial energy

$$= U_f - U_i = 6 \times 10^{-6} - 9 \times 10^{-6}$$
$$= -3 \times 10^{-6}$$

Thus, difference in energy is -3×10^{-6} J.

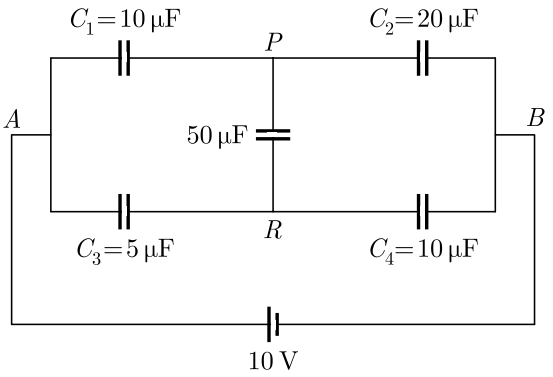
208. Calculate the equivalent capacitance between point A and B in the circuit below. If a battery of 10 V is connected across A and B, calculate the charge drawn from the battery by the circuit.



Ans : SQP 2013, 2011

Since, $\frac{C_1}{C_2} = \frac{C_3}{C_4}$

This is the condition of balance so there will be no current across PR ($50\,\mu\text{F}$ capacitor).

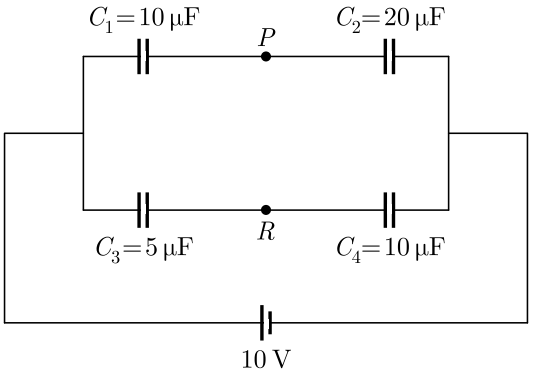


Now, C_1 and C_2 are in series,

$$C_{12} = \frac{C_1 C_2}{C_1 + C_2}$$
$$= \frac{10 \times 20}{10 + 20}$$
$$= \frac{200}{30} = \frac{20}{3}\,\mu\text{F}$$

Since, C_3 and C_4 are in series,

$$C_{34} = \frac{C_3 C_4}{C_3 + C_4}$$
$$= \frac{5 \times 10}{5 + 10}$$
$$= \frac{50}{15} = \frac{10}{3}\,\mu\text{F}$$



Equivalent capacitance between A and B is,

$$C_{AB} = C_{12} + C_{34}$$
$$= \frac{20}{3} + \frac{10}{3} = 10\,\mu\text{F}$$

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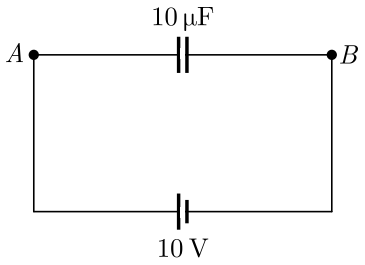
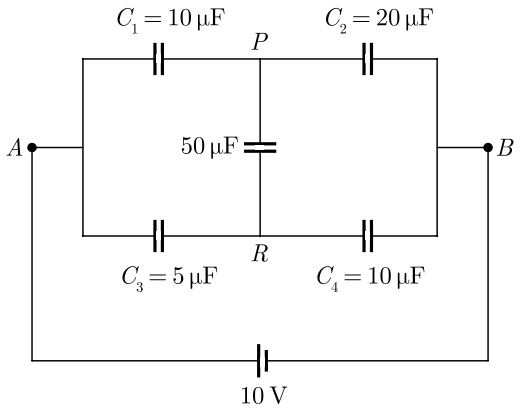


Hence, charge drawn from battery,

$$Q = CV = 10 \times 10\,\mu C$$
$$= 100\,\mu C = 10^{-4}\,C$$

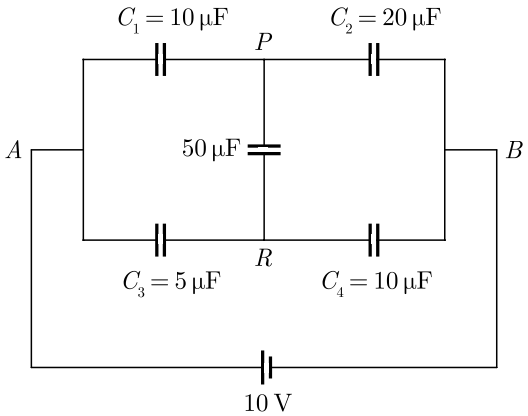
209. Calculate the equivalent capacitance between points A and B in the circuit below. If a battery of 10 V is connected across A and B, calculate the charge drawn from the battery by the circuit.



Ans : **SQP 2016**

$$\frac{C_1}{C_2} = \frac{C_3}{C_4}$$

This is the condition of balance so there will be no current across PR (50 μF capacitor)

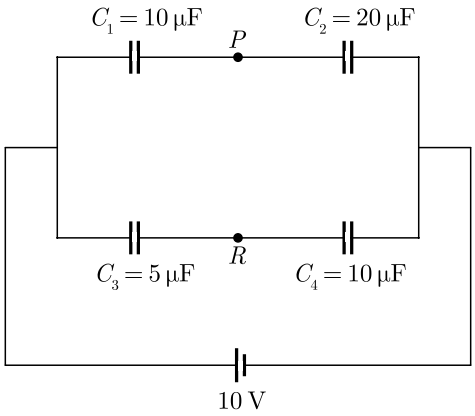


Now, C_1 and C_2 are in series,

$$C_{12} = \frac{C_1 C_2}{C_1 + C_2}$$
$$= \frac{10 \times 20}{10 + 20} = \frac{200}{30} = \frac{20}{3}\,\mu F$$

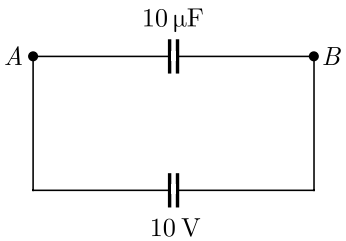
C_3 and C_4 are in series,

$$C_{34} = \frac{C_3 C_4}{C_3 + C_4}$$
$$= \frac{5 \times 10}{5 + 10} = \frac{50}{15} = \frac{10}{3}\,\mu F$$



Equivalent capacitance between A and B is

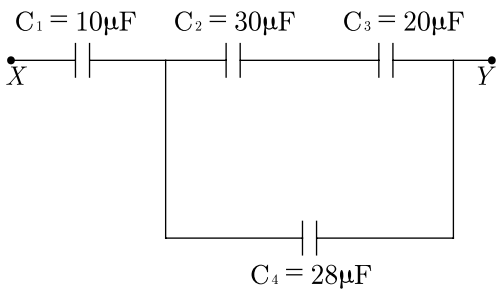
$$C_{AB} = C_{12} + C_{34}$$
$$= \frac{20}{3} + \frac{10}{3} = 10\,\mu F$$



Hence, charge drawn from battery, $Q = CV$

$$= 10 \times 10\,\mu C$$
$$= 100\,\mu C = 10^{-4}\,C$$

210. Four capacitors C_1, C_2, C_3 and C_4 are connected as shown in figure below. Calculate the equivalent capacitance of the circuit between points X and Y.



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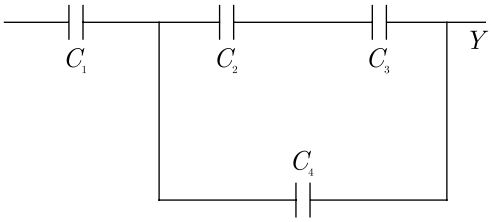
Ans : **Main 2007**

Given, $C_1 = 10\,\mu F$,

$C_2 = 30\,\mu F$,

$C_3 = 20\,\mu F$

$C_4 = 28\,\mu F$



In the figure, C_2 and C_3 are in series, so the equivalent capacitance is given by

$$\frac{1}{C'} = \frac{1}{C_2} + \frac{1}{C_3}$$

Substituting the values of C_2 and C_3, we get

$$\frac{1}{C'} = \frac{1}{30} + \frac{1}{20} = \frac{20+30}{30\times 20}$$

$$C' = \frac{30\times 20}{50} = 12\,\mu F$$

The resultant C' of C_2 and C_3 is in the parallel with C_4. So,

$$C'' = C' + C_4$$

$$= 12 + 28 = 40\,\mu F$$

Now, the resultant C'' of C' and C_4 is in the series with C_1.

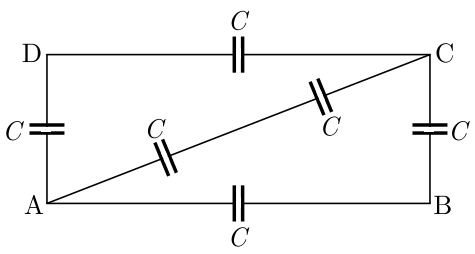
So, the total equivalent capacitance is given by

$$\frac{1}{C_T} = \frac{1}{C''} + \frac{1}{C_1}$$

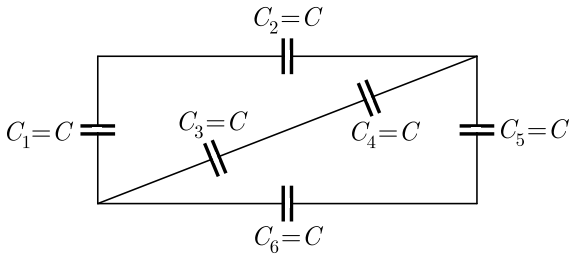
$$= \frac{1}{40} + \frac{1}{10} = \frac{1+4}{40}$$

$$C_T = \frac{40}{5} = 8\,\mu F$$

211. Find equivalent capacitance between A and B.



Ans : **SQP 2011, 2009**



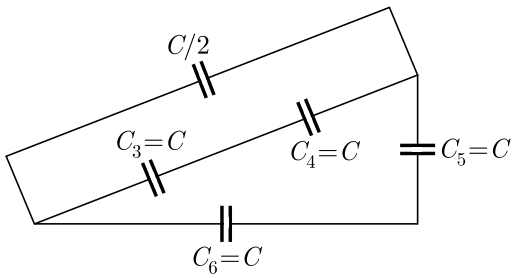
In the above circuit C_1 and C_2 are connected in series combination. Now equivalent capacitance is given by,

$$\frac{1}{C'} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$\frac{1}{C'} = \frac{1}{C} + \frac{1}{C}$$

$$C' = \frac{C}{2}$$

Circuit can be made as follows :



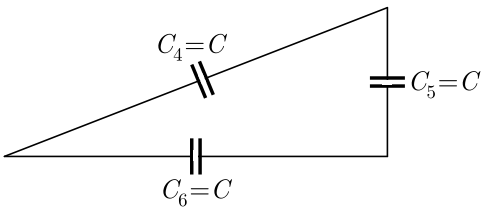
In the circuit C_3 and C_4 are connected in series combination and $C/2$ is in the parallel combination with C_3 and C_4.

Now, $$C'' = \frac{C}{2} + \frac{C\times C}{C+C}$$

$$= \frac{C}{2} + \frac{C}{2}$$

$$= C$$

Now, circuit can be made as follows :



$$C_{eq} = C + \frac{C\times C}{C+C}$$

$$= C + \frac{C}{2} = \frac{3C}{2}$$

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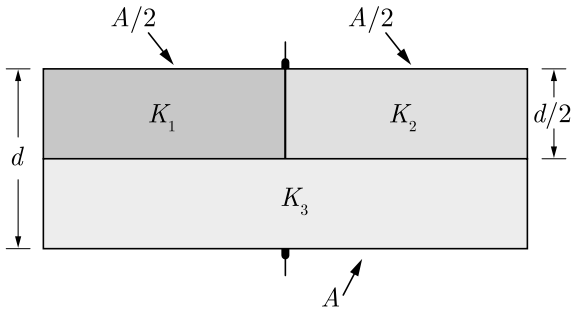
212. A parallel plate capacitor of area A, plate separation d and capacitance C is filled with three different dielectric materials having dielectric constants K_1, K_2 and K_3 as shown in the figure. If a single dielectric material is to be used to have the same capacitance C in this capacitor, what is the value of dielectric constant K ?



A = Area of plates

Ans : **Main 2025**

Given,

Area of parallel plate capacitor $= A$

Plate separation $= d$

Capacitance $= C$

and Different dielectric constants $= K_1, K_2$

and K_3

capacitance of a capacitor,

$$C = \frac{\varepsilon_0 AK}{d}$$

Therefore capacitance of first half potion,

$$C_1 = \frac{\varepsilon_0\left(\frac{A}{2}\right)K_1}{\left(\frac{d}{2}\right)} = \frac{\varepsilon_0 AK_1}{d}$$

Similarly, capacitance of second half portion,

$$C_2 = \frac{\varepsilon_0\left(\frac{A}{2}\right)K_2}{\left(\frac{d}{2}\right)} = \frac{\varepsilon_0 AK_2}{d}$$

and capacitance of third complete portion,

$$C_3 = \frac{\varepsilon_0 AK_3}{\left(\frac{d}{2}\right)} = \frac{2\varepsilon_0 AK_3}{d}$$

We also know that the capacitances C_1 and C_2 are in parallel combination.

Therefore their equivalent capacitance,

$$C_{eq} = C_1 + C_2$$

$$= \frac{\varepsilon_0 AK_1}{d} + \frac{\varepsilon_0 AK_2}{d}$$

$$= \frac{\varepsilon_0 A}{d}(K_1 + K_2)$$

Now, the equivalent capacitance C_{eq} and C_3 are in a series combination. Therefore relation for their resultant capacitance C is,

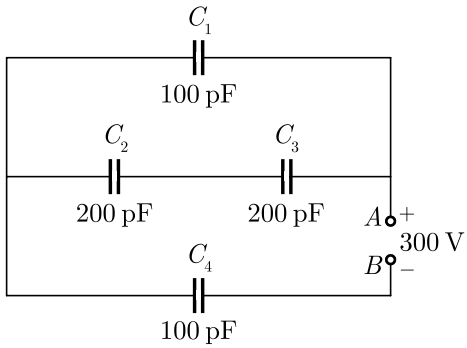
$$\frac{1}{C} = \frac{1}{C_{eq}} + \frac{1}{C_3}$$

$$\frac{d}{\varepsilon_0 AK} = \frac{d}{\varepsilon_0 A(K_1 + K_2)} + \frac{d}{2\varepsilon_0 AK_3}$$

$$\frac{d}{\varepsilon_0 AK} = \frac{d}{\varepsilon_0 A}\left[\frac{1}{(K_1 + K_2)} + \frac{1}{2K_3}\right]$$

$$\frac{1}{K} = \frac{1}{K_1 + K_2} + \frac{1}{2K_3}$$

213. Obtain the equivalent capacitance of the network in figure.



For a 300 V supply, determine the charge and voltage across each capacitor.

Ans : **Main 2011, 2010**

Given, $C_1 = C_4 = 100\,\text{pF}$

$C_2 = C_3 = 200\,\text{pF}$

The capacitors C_2 and C_3 are connected is series. Their equivalent capacitance.

$$C' = \frac{C_2 C_3}{C_2 + C_3}$$

$$= \frac{200 \times 200}{200 + 200} = 100\,\text{pF}$$

The combination of C_2 and C_3 (i.e., C') is connected in parallel with C_1, therefore, equivalent capacitance of C_1 and C'.

$$C'' = C_1 + C'$$

$$= 100 + 100 = 200\,\mu\text{F}$$

The capacitance C'' is in series with C_4, hence equivalent capacitance between A and B

$$C = \frac{C'' C_4}{C'' + C_4} = \frac{200 \times 100}{200 + 100}$$

$$= \frac{200}{3}\,\text{pF} = 66.7\,\text{pF}$$

Total charge, $Q = CV$

$$= \left(\frac{200}{3} \times 10^{-12}\,\text{F}\right) \times (300\,\text{V})$$

$$= 2 \times 10^{-8}\ \text{coulomb}$$

As C_4 is connected in series with battery, charge on C_4 is

$$Q_4 = 2 \times 10^{-8}\,\text{C}$$

Potential difference across C_4 is

$$V_4 = \frac{Q_4}{C_4} = \frac{2 \times 10^{-8}\,\text{C}}{100 \times 10^{-12}\,\text{F}} = 200\,\text{V}$$

As C_2 and C_3 have resultant capacitance C' equal to $C_1 = 100\,\text{pF}$, so the charge Q is equally divided among two branches; charge on C_1 is

$$Q_1 = \frac{Q}{2} = \frac{2 \times 10^{-8}}{2}$$

$$= 1 \times 10^{-8}\,\text{C} = 10^{-8}\,\text{C}$$

Charge in branch C_2 and C_3 is also $1 \times 10^{-8}\,\text{C}$. As charge in series remains same, so charge on C_2 and C_3 are equal to $1 \times 10^{-8}\,\text{C}$.

$$Q_2 = Q_3 = 10^{-8}\,\text{C}$$

Potential difference across,

$$C_1 = V_1 = \frac{Q_1}{C_1}$$

$$= \frac{10^{-8}}{100 \times 10^{-12}} = 100\,\text{V}$$

Potential difference across,

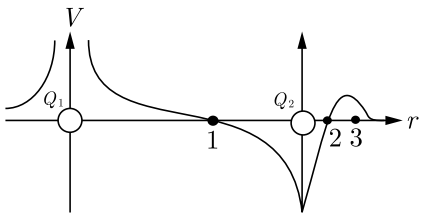
$$C_2 = \frac{Q_2}{C_2} = \frac{10^{-8}}{200 \times 10^{-12}} = 50\,\text{V}$$

Potential difference across,

$$C_3 = \frac{Q_3}{C_3} = \frac{10^{-8}}{200 \times 10^{-12}} = 50\,\text{V}$$

CASE BASED QUESTIONS

214. The potential at any observation point P of a static electric field is defined as the work done by the external agent (or negative of work done by electrostatic field) in slowly bringing a unit positive point charge from infinity to the observation point. Figure shows the potential variation along the line of charges. Two-point charges Q_1 and Q_2 lie along a line at a distance from each other.



(i) At which of the points 1, 2 and 3 is the electric field is zero?

(ii) What is the nature of charge Q_1 and Q_2?

(iii) Which of the two charges Q_1 and Q_2 is greater in magnitude?

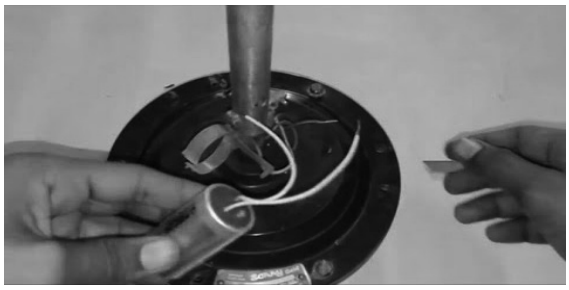
Ans :

(i) 3

(ii) Positive and negative

(iii) Q_1

215. In Akash's classroom the fan above the teacher was running very slowly. Due to which his teacher was sweating and was restless and tired. All his classmates wanted to rectify this. They called for an electrician who came and changed the capacitor only after which the fan started running fast.



(i) What energy is stored in the capacitor and where?

(ii) Does capacitor affect fan speed?

(iii) How does a capacitor control fan speed?

Ans :

(i) Electrical energy in the dielectric of the capacitor.

(ii) When you increase the capacitance, the fan motor's voltage goes up, but the capacitor's goes down. The fan's speed goes up. To increase the fan speed, you need to increase the capacitor value.

(iii) They control the voltage across the fan is controlled by a capacitor, the voltage across the fan determines the fan speed. Capacitive regulators are energy efficient with linear speed control, quiet operation without humming noises and highly reliable than electronic type regulator.

216. A dielectrics is an insulating material in which all the electrons are tightly bound to the nuclei of the atoms. Thus, there are no free electrons to carry current. Hence, the electrical conductivity of a dielectric is very low. (The conductivity of an ideal dielectric is zero). Glass, plastic, mica, oil, etc. are examples of dielectrics.

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It is found experimentally that when a dielectric material is placed between the plates of a capacitor, the capacitance of the capacitor increases by a dimensionless factor K which is called the "dielectric constant" or "Specific Inductive capacity of the material." Thus,

$$C = KC_0 \text{ or } K = \frac{C}{C_0}$$

(i) Will a dielectric-filled capacitor store more charge or less charge than a similar air capacitor at the same potential differences?

(ii) How is dielectric constant (or relative permittivity of a dielectric expressed in terms of capacitance?

(iii) What may be a possible reason of water having a much greater dielectric constant (= 80) than say mica (6)?

(iv) In a parallel-plate capacitor, the capacitance increases from $4\,\mu F$ to $80\,\mu F$ on introducing a dielectric medium between the plates. What is the dielectric constant of the medium.

(v) If the dielectric medium is a solid substance, then is there any other advantages of it in addition to an increase in the capacitance?

Ans :

(i) More charge, because the capacitance of a dielectric filled capacitor is larger than that if an air filled capacitor and $Q = CV$.

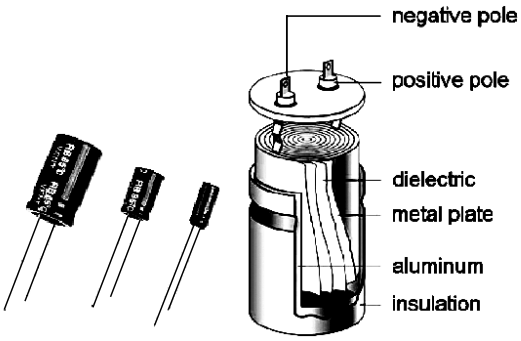
(ii) $K = C/C_0$, where C is the capacitance of a capacitor filled completely with the dielectric and C_0 that of the same capacitor with vacuum (or air) between the plates.

(iii) Water molecules have permanent dipole moments. That's why water having a much greater dielectric constant (= 80) than say mica (= 6).

(iv) $K = \frac{C}{C_0} = \frac{80\,\mu F}{4\,\mu F} = 20$

(v) Yes, it helps in keeping the plates of the capacitor very close to each other without touching.

217. Shikhaj was working on a project for science exhibition. He considered a capacitance of $2\,\mu F$ having a capacity of operating under 1 kV potential. When he reached to shop, he found that the shopkeeper is having a capacitors of $1\,\mu F$ of 400 V rating. Shikhaj calculated minimum number of capacitance of $1\,\mu F$ each so he could arrange to form a capacitor of $2\,\mu F$.



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(i) What are the calculations done by Shikhaj ?

(ii) Can there be a potential difference between two conductors of the same volume carrying equal positive charge?

(iii) Is a dielectric a conductor?

Ans :

(i) Total potential difference across each row = 1000 Volt

Potential difference across each capacitor = 400 Volt

Number of capacitors in series

$$n = \frac{1000}{400} = 2.5 \simeq 3$$

Capacitance of capacitors in series,

$$C_S = \frac{1}{3} = 2$$

$$m = 6$$

Hence total number of capacitance required

$$= m \times n = 6 \times 3 = 18$$

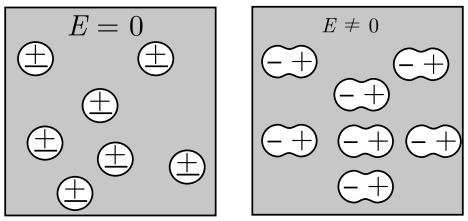
Total 6 row of capacitor in parallel with three capacitors in each row.

(ii) Yes, Because two conductors of the same volume may have different shapes and hence difference capacitances.

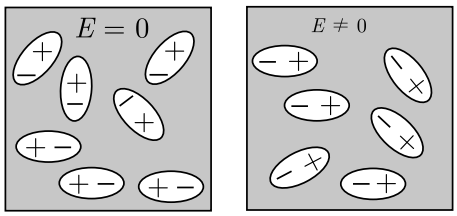
(iii) Dielectric materials are poor conductors of electricity because they do not have any loosely bound or free electrons that may drift through the material. Electrons are required to support the flow of an electric current.

218. Dielectric with polar molecules also develops a net dipole moment in an external field, but for a different reason. In the absence of any external field, the different permanent dipoles are oriented randomly due to thermal agitation; so the total dipole moment is zero. When an external field is applied, the individual dipole moments tend to align with the field. When summed overall the molecules, there is then a net dipole moment in the direction of the external field, i.e., the dielectric is polarised. The extent of polarisation

depends on the relative strength of two factors. The dipole potential energy in the external field tending to align the dipoles mutually opposite with the field and thermal energy tending to disrupt the alignment. There may be, in addition, the 'induced dipole moment' effect as for non-polar molecules, but generally the alignment effect is more important for polar molecules. Thus in either case, whether polar or non-polar, a dielectric develops a net dipole moment in the presence of an external field. The dipole moment per unit volume is called polarization.



(a) Non-Polar molecules



(b) Polar molecules

(i) What do you mean by dielectric polarization?

(ii) Calculate the polarisation vector of the material which has 100 dipoles per unit volume in a volume of 2 units?

(iii) In which type of molecule positive and negative charges coincide with each other ?

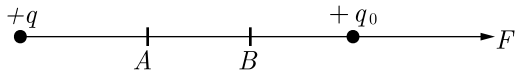
Ans :

(i) Dielectric polarization is the term given to describe the behaviour of a material when an external electric field is applied to it. It occurs when a dipole moment is formed in an insulting material because of an externally applied electric field.

(ii) 50

(iii) Non polar, A molecule in which the centre of mass of positive and negative charges collide with each other is called a non-polar molecule. They normally have zero dipole moment. They have symmetrical shapes.

219. In definition of potential, the reference point (of zero potential) is taken at infinity (outside the field). If we take two points A and B in the electric field (figure) then potentials at A and B will be defined as above.



The difference in there potentials is termed as potential difference between the points A and B.

Independently, it is defined as follows

"The work done by an external agent in carrying a unit positive test charge from one point to the other point in an electric field is called the potential difference between those points."

If W be the work done in carrying the test charge go from B to A, then the potential difference between A and B is given by

$$V_A - V_B = W/q_0$$

(i) How much work is done in taking an electron around a nucleus in a circular path?

(ii) We assume the potential of earth zero. Can it be assumed +100 V? What will be the effect of it on the measurement of electric potential at a point? On the potential difference between two points?

(iii) A charge of 3 C moving in a uniform electric field experiences a force of 3000 N. The potential difference between two points situated in the field at a distance 1 cm from each other will be ..... .

(iv) 2 J work is done in taking a charge of 20 C from one point to the other at a distance of 0.2 mV. What is the potential difference between the points?

(v) What do you mean by 1 eV?

Ans :

(i) Orbit of an electron around the nucleus is equipotential, i.e. potential difference between any two points of this orbit is zero and further since work done,

$$W = q \times \Delta V$$

$$(\Delta V = 0)$$

$$W = 0$$

(ii) Yes, it can be assumed the measurement of potential at every point will be increased by 100 V, no effect on potential difference.

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(iii) Given, $F = 3000$ N, $q = 3$ C

$$E = \frac{F}{q} = \frac{3000}{3}$$

$$= 1000 \text{ V/m}$$

Potential difference

$$V = Ed$$

$$= 1000 \text{ V/m} \times 0.01 \text{ m}$$

$$= 10 \text{ V}$$

(iv) $$V_A - V_B = \frac{W}{q_0}$$

$$W = 2 \text{ J}$$

$$q_0 = 20 \text{ C}$$

$$V_A - V_B = \frac{2}{20} = 0.1 = 1 \times 10^{-1} \text{ V}$$

(v) 1 electron-volt is the work done in taking one electron from one point to the other, when the potential difference between these points is 1 V.

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

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CHAPTER 3

Current Electricity

SUMMARY

1. ELECTRIC CURRENT

It is defined as the rate of flow of electric charge through any cross-section of a conductor, i.e.

$$I = \left(\frac{dq}{dt}\right)$$

The direct rate of flow of electric charge through any cross-section of a conductor is known as electric current.

$$I = \frac{q}{t} = \frac{ne}{t} \qquad [\text{since } q = ne]$$

where, n = number of charged particles constitute the current.

2. CURRENT DENSITY

It is the ratio of the current at a point in conductor to the area of cross-section of the conductor at the point, i.e.

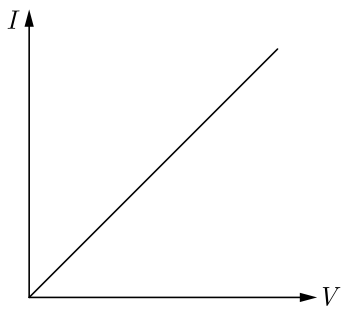
$$J = \frac{I}{A}$$

3. OHM'S LAW

At constant temperature, the potential difference V across the ends of a given metallic wire (conductor) in an circuit (electric) is directly proportional to the current flowing through it.

$$V \propto I$$

The variation of current w.r.t. applied potential difference is shown with the help of given graph.



$$V = IR$$

where, R = resistance of conductor

4. FLOW OF ELECTRIC CHARGES IN METALLIC CONDUCTORS

In case of solid conductor, large number of free electrons causes the strong current in them.

In the case of a liquid conductor, movement of positive and negative charged ions causes the electric current.

5. RESISTANCE OF A CONDUCTOR

Mathematically, it is the ratio of potential difference applied across the ends of conductor to the current flowing through it.

$$R = \frac{V}{I}$$

SI unit is ohm (Ω),

Resistance can also be written as,

$$R = \rho\frac{L}{A}$$

where, L = length of the conductor

A = area of cross-section

and ρ = constant, known as resistivity of the material

It depends upon nature of the material.

6. EFFECT OF TEMPERATURE ON RESISTANCE

For metals, resistance increases with rise in temperature. For insulators and semiconductors, resistance decreases with rise in temperature. For alloy, temperature coefficient of resistance is small.

Temperature coefficient of resistance is given by,

$$\alpha = \frac{R_2 - R_1}{R_1(t_2 - t_1)}$$

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7. DRIFT VELOCITY

It is defined as the average velocity with which the free electrons move towards the positive end of a conductor under the influence of an external electric field applied.

$$v_d = \frac{eE}{m}\tau$$

where, τ = relaxation time

E = electric field

m = mass

and e = charge on electron

8. RELATION BETWEEN DRIFT VELOCITY AND ELECTRIC FIELD

The relation between drift velocity and electric field is given by

$$I = neAv_d$$

where, n = number density of free electrons

e = electronic charge

A = cross-sectional area

and v_d = drift velocity of an electron

The ratio of drift velocity of electron and the applied electric field is known as mobility.

$$\mu = \frac{v_d}{E} = \frac{q\tau}{m}$$

Hence, SI unit is $[m^2s^{-1}V^{-1}]$.

8.1 Relationship between Resistivity and Relaxation Time

The relationship between resistivity and relation time is given by.

$$\rho = \frac{m}{ne^2\tau}$$

Where, τ = relaxation time

Specific resistance or resistivity ρ depends on the material of conductor, not on the length and cross-sectional area A, i.e. geometry of conductor.

9. RESISTIVITY

It is the resistance of a unit length with unit area of cross-section of the material of the conductor.

9.1 Effect of Temperature on Resistivity

For metals, resistivity increases with increase in temperature.

For alloys, resistivity is very large but has a weak dependence on temperature.

10. CLASSIFICATION OF MATERIALS IN TERMS OF CONDUCTIVITY

For insulators, electrical conductivity is very small or nil. For conductors, electrical conductivity is very high. For semiconductors, electrical conductivity lies in between that of insulators and conductors.

11. CONDUCTANCE AND CONDUCTIVITY

Conductance is the reciprocal of resistance of conductor. Conductivity is the reciprocal of the resistivity of conductor.

Electrical Conductivity is a property of the material it sell white electrical Conductivity is a property of a particulars electrical component the unit of conductance of semen and it is the reciprocal of the ohm. the unit of conduct unity are sometimes given as ohms/ meter.

12. ELECTRICAL ENERGY

Electrical energy is the total work done in maintaining the electric current in the given circuit for a specified time.

NODIA

13. ELECTRICAL POWER

Electrical power is the rate of electrical energy supplied per unit time to maintain flow of electric current through conductor.

14. ELECTROMOTIVE FORCE OF A CELL EMF

It is the maximum potential difference between two terminals of circuit, when circuit is open.

15. INTERNAL RESISTANCE

The resistance offered by the electrolyte of the cell, to the flow of current through it.

16. TERMINAL POTENTIAL DIFFERENCE

It is the maximum potential difference between two terminals of circuit, when the circuit is closed.

17. THE RELATIONSHIP BETWEEN r, R, E AND V IS

$$r = R\left(\frac{E}{V} - 1\right) \quad ...(1)$$

where, r = internal resistance

R = external resistance

E = emf of cell

V = terminal voltage of cell

Also, $V = E - Ir = \left(\frac{E}{R+r}\right)R$ ...(2)

18. COMBINATION OF CELLS

In series grouping, current is given by,

$$I = \left(\frac{n\varepsilon}{R+nr}\right)$$

In parallel grouping, current is given by,

$$I = \left(\frac{m\varepsilon}{r+mR}\right)$$

In mixed grouping, current is given by,

$$I = \left(\frac{mn\varepsilon}{nr+mR}\right)$$

19. KIRCHHOFF'S LAWS

Kirchhoff's laws are fundamental rules used to analyze complex electrical circuits where simple series-parallel combinations are not sufficient. These laws, given by Gustav Kirchhoff in 1845, are based on the conservation of charge and energy.

1. **First Law** (Junction Rule) : The algebraic sum of the currents meeting at a point in an electrical circuit is always zero.
2. **Second Law** (Loop Rule) : The algebraic sum of changes in potential around any closed loop involving resistors and the cells in the loop is zero.

20. WHEATSTONE BRIDGE

It is an arrangement of four resistances used to measure one of them in terms of another three. The bridge is said to be balanced when the galvanometer shows zero deflection.

The balance condition is,

$$\frac{P}{Q} = \frac{R}{S}$$

21. METER BRIDGE

It is also known as slide wire bridge. It is a practical form of Wheatstone bridge.

The unknown resistance is given by

$$S = R \times \left(\frac{100-l}{l}\right)$$

22. POTENTIOMETER

It is an apparatus used to compare emf's of two cells of to measure the internal resistance of a cell.

Comparison of the emfs of two cells.

i.e. $\frac{E_1}{E_2} = \frac{l_1}{l_2}$

where, l_1 and l_2 are the balancing lengths corresponding to cells of emf E_1 and E_2, respectively.

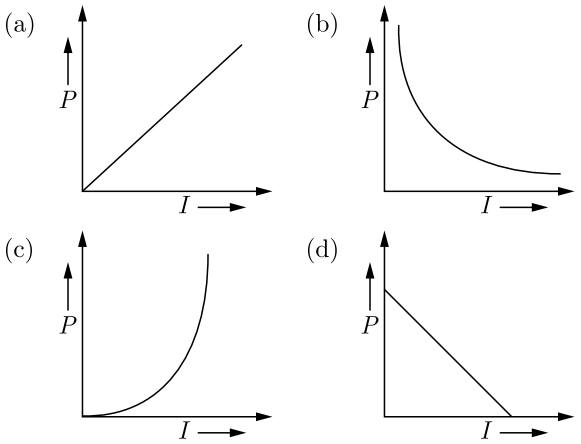
Comparison of the internal resistance of a primary cell.

i.e. $r = R\left(\frac{l_1}{l_2} - 1\right)$

where, l_1 and l_2 are balancing lengths and R is applied resistance.

OBJECTIVE QUESTIONS

1. An electric current (I) flowing through a metallic wire is gradually increased. The graph of heating power (P) developed in it versus the current (I) is



Ans : **Main 2023**

Heating power (P) is directly proportional to I^2

As, $H = VIt$

Applying ohm's law, $H = I^2Rt$. From this equation, we can conclude that the heat produced is directly proportional to the square of electric current.

Thus (c) is correct option.

2. The drift velocity of a current carrying conductor is v. What will be the drift velocity if the current flowing through the wire is doubled?

(a) $v/4$ (b) $v/2$

(c) $2v$ (d) $4v$

Ans : **Main 2022 Sem-I**

$$I = neAv_d$$

$$v_d \propto I$$

If current is doubled then v_d will become double.

Thus (c) is correct option.

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3. SI unit of electrical conductivity is

(a) Ωm^{-1} (b) Ωm^{-2}

(c) $\Omega^{-1}m^{-1}$ (d) $\Omega^{-1}m^{-2}$

Ans : **SOP 2021**

Electrical conductivity,

$$\sigma = \frac{1}{\rho}$$

$$\text{S.I. Unit} = \frac{1}{\Omega - m} = \Omega^{-1}m^{-1}$$

Thus (c) is correct option.

4. In current electricity, Ohm's law is obeyed by all

(a) solids (b) metals

(c) liquids (d) gases

Ans : **Main 2011**

Ohm's law is obeyed by all metals, provided temperature remains unchanged.

Thus (b) is correct option.

5. A metallic wire of resistance R is stretched slowly and uniformly (keeping its temperature constant) till its new radius becomes half. Its resistance, then becomes

(a) $16R$ (b) $8R$

(c) $4R$ (d) R

Ans : **Main 2022 Sem-I**

As, $$R = \rho \cdot \frac{l}{A} = \rho \cdot \frac{l \cdot A}{A^2}$$

$$= \rho \cdot \frac{V}{A^2} = \rho \cdot \frac{V}{(\pi r^2)^2}$$

$$R \propto \frac{1}{r^4}$$

$$\frac{R'}{R} = \left(\frac{r}{r'}\right)^4 = \left(\frac{r}{r/2}\right)^4 \qquad \left[r' = \frac{r}{2}\right]$$

$$= (2)^4 = 16$$

$$R' = 16R$$

Thus (a) is correct option.

6. Specific resistance of the material of a wire depends on

(a) length of the wire.

(b) area of cross-section of the wire.

(c) volume of the wire.

(d) temperature of the wire.

Ans : **Main 2022 Sem-I**

The Specific resistance of a wire depends on the temperature on the material the is used in wire. Specific resistance is depends as the resistance offered per unit length and unit cross-section and when a voltage of none value is applied.

Thus (d) is correct option.

7. The resistance of a wire is $10\,\Omega$. It is stretched so that its length becomes four times. What will be the new resistance of the wire?

(a) $40\,\Omega$ (b) $160.0\,\Omega$

(c) $120\,\Omega$ (d) $80.0\,\Omega$

Ans : **Main 2025 Sem-I**

$$R = 10\,\Omega$$

As, $$R = \frac{\rho L}{A} \qquad ...(1)$$

Where ρ = Specifier resistance

From volume $AL = A'L'$

$$L' = 4L$$

From Eq.(1), $A' = A/4$

So, new resistance,

$$R' = \frac{\rho L'}{A'}$$

$$R' = \frac{\rho 4L}{A/4} = 16R$$

So, new resistance $= 16R = 16 \times 10 = 160\,\Omega$

Thus (b) is correct option.

8. With reference to the free electron theory of conductors,

(i) Drift velocity is

(a) the average velocity of free electrons with which they move towards the positive terminal.

(b) the velocity of free electrons with which they move towards the positive terminal.

(c) the average speed of free electrons with which they move towards the negative terminal.

(d) the speed of free electrons with which they move towards the negative terminal.

(ii) Relaxation time is

(a) the time interval between number of collisions of a free electron in a conductor.

(b) the average time interval between two successive collisions of a free electron with metallic ions in a conductor.

(c) the time interval between number of collisions of metal ions in a conductor.

(d) the time interval between collision of free electrons with each other.

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Ans : Main 2022 Sem-I

(i) (a) the average velocity of free electrons with which they move towards the positive terminal

(ii) (b) the average time interval between two successive collisions of a free electron with metallic ions in a conductor

9. A cell of emf E is connected to an external resistance R. The potential difference across cell is V. The internal resistance of cell will be

(a) $\frac{(E-V)R}{E}$ (b) $\frac{(E-V)R}{V}$

(c) $\frac{(V-E)R}{V}$ (d) $\frac{(V-E)R}{E}$

Ans : Main 2025 Sem-I

Let the current in the circuit, $I = \frac{V}{R}$

Across the cell, $E = V + Ir$

$$r = \frac{E-V}{I} = \frac{E-V}{\frac{V}{R}}$$

$$= \left(\frac{E-V}{V}\right)R$$

Thus (b) is correct option.

10. n identical cells each of emf E and internal resistance r are connected in parallel. An external resistance R is connected in series to this combination. The current through R is

(a) $\frac{nE}{R+nr}$ (b) $\frac{nE}{nR+r}$

(c) $\frac{E}{R+nr}$ (d) $\frac{nE}{R+r}$

Ans : Main 2022 Sem-I

Total resistance of circuit

$$= R + \frac{r}{n}$$

$$\text{Current, } I = \frac{E}{R+\frac{r}{n}} = \frac{nE}{nR+r}$$

Thus (b) is correct option.

11. Four identical cells each having an emf of 4 V are connected in parallel. What will be the emf of this combination?

(a) 1 V (b) 16 V

(c) 1/4 V (d) 4 V

Ans : Main 2022 Sem-I

In the parallel combination difference or emf are same. The combined emf is 4 V.

Thus (d) is correct option.

12. A 2 V battery, a 15 Ω resistor and a potentiometer of 100 cm length, all are connected in series. If the resistance of potentiometer wire is 5 Ω, then the potential gradient of the potentiometer wire is ..... .

(a) 0.005 V/cm (b) 0.05 V/cm

(c) 0.02 V/cm (d) 0.2 V/cm

Ans : Main 2022 Sem-I

$$\text{Potential gradient} = \frac{e}{(R+R_w+r)} \times \frac{R}{L}$$

$$= \frac{2}{(15+5+0)} \times \frac{5}{1}$$

$$= 0.5\,\frac{\text{V}}{\text{m}} = 0.005\ \text{V/cm}$$

Thus (a) is correct option.

13. In an experiment of meter bridge, a null point is obtained at the centre of the bridge wire. When a resistance of 5 is connected in one gap, what is the value of resistance in the other gap?

(a) 10 Ω (b) 5 Ω

(c) 1/5 Ω (d) 500 Ω

Ans : Main 2024 Sem-I

$$\frac{P}{Q} = \frac{R}{S}$$

As, $P = Q$

$$1 = \frac{R}{S}$$

$$S = 5\,\Omega$$

Thus (b) is correct option.

14. The potential gradient along the length of a uniform wire is 20 V/m. B and C are the two points at 40 cm and 70 cm point on a meter scale fitted along the wire. What is the potential difference between B and C ?

(a) 6 V (b) 0.4 V

(c) 0.6 V (d) 4 V

Ans : Main 2022 Sem-I

Two points at 40 cm and 70 cm point on meter scale fitted along the wire.

Let potential difference between B and C is

$$K = \frac{E}{L} = 20\ \text{V/m}$$

$$E = K\,.\,L = 20 \times (0.70 - 0.40)$$

$$= 20 \times 0.3 = 6\ \text{V}$$

Thus (a) is correct option.

15. Wheatstone bridge principle is used to measure

(a) resistance of a wire

(b) potential difference across a resistor

(c) current flowing through a wire

(d) emf of a cell

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Ans : **Main 2024 Sem-I**

The Wheatstone bridge is a special arrangement of four resistors used to find the unknown resistance of a wire or a resistor. When the bridge is balanced, no current flows through the galvanometer, and we can calculate the unknown resistance using the relation:

$$P/Q = R/S$$

The correct option is (a).

16. If potential difference across 80 cm of a potentiometer wire is 2 V, potential gradient across the wire is

(a) 0.025 Vm^{-1} (b) 0.050 Vm^{-1}

(c) 0.075 Vm^{-1} (d) 2.50 Vm^{-1}

Ans : **Main 2022 Sem-I**

$$E = 2\text{ V},\ l = 80\text{ cm} = 0.8\text{ m}$$

Potential gradient

$$(K) = \frac{E}{l} = \frac{2}{0.8} = 2.5\ Vm^{-1}$$

Thus (d) is correct option.

17. In a potentiometer, balancing length with a standard cell of emf 1.08 V is 21.6 cm. Balancing length with a cell of emf 1.50 V will be

(a) 21.6 cm (b) 30.0 cm

(c) 45.0 cm (d) 60.0 cm

Ans : **Main 2022 Sem-I**

$$E_1 = 1.08\text{ V},\ l_1 = 21.6\text{ cm}$$

$$E_2 = 1.50\text{ V},\ l_2 = ?$$

At the balancing point in a potentiometer,

$$\frac{E_2}{E_1} = \frac{l_2}{l_1}$$

$$l_2 = \left(\frac{E_2}{E_1}\right)l_1 = \left(\frac{1.50}{1.08}\right) \times 21.6$$

$$= 30\text{ cm}$$

Thus (b) is correct option.

18. If R_1 and R_2 are filament resistances of a 100 W bulb and a 50 W bulb respectively, designed to operate on the same voltage then

(a) $R_1 = R_2$ (b) $R_1 = 4R_2$

(c) $R_2 = 4R_1$ (d) $R_2 = 2R_1$

Ans : **Main SQP 2023**

Power of bulb is inversely proportional to the resistance of filament wire of bulb.

$$\frac{P_1}{P_2} = \frac{R_2}{R_1}$$

$$\frac{100}{50} = \frac{R_2}{R_1}$$

$$\frac{R_2}{R_1} = 2$$

$$R_2 = 2R_1$$

Thus (d) is correct option.

19. An electric bulb is marked 200 V, 50 W. If it is used on a 400 V supply, it will draw a current of

(a) 0.25 A (b) 0.40 A

(c) 0.50 A (d) 0.80 A

Ans : **Main 2022 Sem-I**

Bulb rating = 200 V, 50 W

$$R = \frac{V^2}{P} = \frac{200 \times 200}{50} = 800\ \Omega$$

Now $$I = \frac{V'}{R} = \frac{400}{800} = \frac{1}{2} = 0.50\text{ A}$$

Thus (c) is correct option.

20. A current of 0.8 A flows in a conductor of 40 Ω for 1 minute. The heat produced in the conductor will be

(a) 1445 J (b) 1536 J

(c) 1569 J (d) 1640 J

Ans : **Main 2023**

$$\text{Time} = 1\text{ min} = 60\text{ sec}$$

$$\text{Current, } I = 0.8\text{ A}$$

$$\text{Resistance, } R = 40\ \Omega$$

$$\text{Heat produced } I^2Rt = (0.8)^2 \times 40 \times 60$$

$$= 1536\text{ J}$$

Thus (b) is correct option.

21. A cell of emf E is connected across an external resistance R. When current I is drawn from the cell, the potential difference across the electrodes of the cell drops to V. The internal resistance 'r' of the cell is

(a) $\left(\frac{E-V}{E}\right)R$ (b) $\left(\frac{E-V}{R}\right)$

(c) $\left(\frac{E-V}{I}\right)R$ (d) $\left(\frac{E-V}{V}\right)R$

Ans : **SQP 2023**

From ohm's law, let the current in the circuit,

$$i = \frac{V}{R}$$

PD across the cell, $E = V + it$

$$r = \frac{E-V}{i} = \frac{E-V}{V/R}$$

$$= \left(\frac{E-V}{V}\right)R$$

Thus (d) is correct option.

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22. Pieces of copper and silicon are initially at room temperature. Both are heated to temperature T. The conductivity of

(a) both increases.

(b) both decreases.

(c) copper increases and silicon decreases.

(d) copper decreases and silicon increases.

Ans : **Main 2023**

Copper is a conductor and hence its conductivity decreases with increase in temperature. Silicon is a semiconductor and hence its conductivity increases with increase in temperature.

Thus (d) is correct option.

23. Which element is used in electric heater?

(a) Copper (b) Platinum

(c) Tungsten (d) Nichrome

Ans : **SQP 2017**

Nichrome is used in electric heater because of the following reasons :

1. Its melting point is high.
2. Its resistivity is large.
3. It is not easily oxidised by the oxygen of the air when heated.

Thus (d) is correct option.

24. Kilowatt-hour (kWh) is the unit of.

(a) energy (b) power

(c) torque (d) force

Ans : **Main 2015, 2010**

The bigger unit of electric energy is kilowatt hour.

$$1\,\text{kW} = 1000\,\text{W}$$

$$1\,\text{kWh} = 3.6 \times 10^6\,\text{J}$$

Thus (a) is correct option.

25. To increase sensitivity of a potentiometer, its

(a) area should be increased.

(b) current should be decreased.

(c) current should be increased.

(d) length should be increased.

Ans : **SQP 2009, 2007**

The sensitivity of potentiometer can be increased by reducing the potential gradient. This can be done in two way-

1. The sensitivity can be increased by increasing the length of the potentiometer wire.
2. For a potentiometer wire of fixed length, the potential gradient can be decreased by reducing the current in the circuit with the help of rheostat.

Thus (b) is correct option.

26. The net charge on a current carrying conductor is

(a) zero (b) constant

(c) varying (d) negative

Ans : **Main 2017**

number of protons in a current carrying conductor at any instant is equal to the number of free electrons. Therefore, the net charge on a current carrying conductor is zero.

Thus (a) is correct option.

27. A steady current flows in a metallic conductor of non-uniform cross-section. Which of the following quantity is constant along the conductor?

(a) current (b) drift speed

(c) current density (d) none of these

Ans : **SQP 2009**

Current remains constant through a conductor of non-uniform cross-section, because of the steady state.

In this case, the charge entering at one section is equal to the charge leaving at any other section.

Thus (a) is correct option.

28. The resistance of an incandescent lamp is

(a) greater when switched ON

(b) smaller when switched ON

(c) greater when switched OFF

(d) same whether it is switched OFF or ON.

Ans : **Main 2007**

Resistance of an incandescent lamp depends upon the nature of the material used, its dimensions and physical conditions.

Therefore it does not effect whether the lamp is switched OFF or ON. In other words, the resistance remains the same whether the bulb is switched off or on.

Thus (d) is correct option.

29. Wheatstone's bridge is used in measuring

(a) High resistance

(b) Low resistance

(c) Both high and low resistance

(d) Potential difference

NODIA

Ans : SQP 2017, 2015

Wheatstone bridge can be used for the measurement of low resistances only.

Thus (b) is correct option.

30. Electron-volt (eV) is the measure of

(a) charge

(b) potential difference

(c) current

(d) energy

Ans : Comp 2016, 2015

Electron-volt (eV) is a unit of energy equal to approximately 1.602×10^{-19} J. By definition it is the amount of energy gained by the charge of a single electron moved across an electric potential difference of one volt.

Thus (d) is correct option.

31. If voltage across a lamp increases by 2%, then increase in its power will be

(a) 1% (b) 2%

(c) 3% (d) 4%

Ans : Main 2014

Increase in voltage $= 2\%$

Power of lamp, $P = \frac{V^2}{R} \propto V^2$

Therefore, if voltage increases by 2%, then increase in its power will be 4%.

Thus (d) is correct option.

32. Potential difference between two electrodes of a galvanic cell in an open circuit is known as

(a) current

(b) impedance

(c) voltage

(d) electromotive force

Ans : Main 2012

In an open circuit, no current is drawn from the cell. And the potential difference between two electrodes of a galvanic cell, in an open circuit is known as electromotive force of the cell.

Thus (d) is correct option.

33. Which of the following is a non-ohmic resistor?

(a) copper (b) aluminium

(c) diode-valve (d) none of these

Ans : Main 2008

A diode-valve is a non-ohmic resistor, because the relation between voltage and resulting current is not linear.

Thus (c) is correct option.

34. The algebraic sum of all currents meeting at a point in an electrical circuit is

(a) zero (b) infinite

(c) positive (d) negative

Ans : SQP 2016, 2015

According to the Kirchhoff's first law "In an electric circuit, the algebraic sum of current at any junction is zero or the sum of currents entering a junction is equal to the sum of currents leaving that junction.

Thus (a) is correct option.

35. If the resistivity of an alloy is $\rho'$and that of its constituent metal is ρ, then

(a) $\rho' < \rho$ (b) $\rho' > \rho$

(c) $\rho' = \rho$ (d) none of these

Ans : SQP 2013

Resistivity of alloy $= \rho'$

and Resistivity of its constituent metal $= \rho$

resistivity of a metal increases, when it is converted into an alloy. Therefore,

$$\rho' > \rho$$

Thus (b) is correct option.

36. An energy source will supply a constant current into the load, if its internal resistance is

(a) zero

(b) equal to load resistance

(c) very large than load resistance

(d) non-zero but less than load resistance

Ans : SQP 2013

current in the circuit,

$$I = \frac{E}{R + r}$$

Therefore an energy source will supply a constant current equal to $\frac{E}{R}$ into the load if its internal resistance r is zero.

Thus (a) is correct option.

37. The internal resistance of a cell is the actual resistance of

(a) electrodes of the cell

(b) vessel of the cell

(c) material used in the cell

(d) electrolyte used in the cell

Ans : SQP 2011

Resistance offered by the electrolyte of a cell, when electric current flows from negative terminal to

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positive terminal through it is known as internal resistance of the cell. And it is denoted by r.

Thus (d) is correct option.

38. What is the resistance of a 40 W lamp which is lighted as full brilliance by a current of $\frac{1}{3}$ A?

(a) 120 Ω (b) 240 Ω

(c) 360 Ω (d) 480 Ω

Ans : SQP 2008

Power of lamp, $P = 40$ W

Current, $I = \frac{1}{3}$ A

resistance of lamp,

$$R = \frac{P}{I^2} = \frac{40}{\left(\frac{1}{3}\right)^2} = 360\,\Omega$$

Thus (c) is correct option.

39. Absorbed electrical energy is

(a) Proportional to the potential difference

(b) Inversely proportional to the potential difference

(c) Proportional to the square of the potential difference

(d) None of these

Ans : SQP 2017, 2015

Electrical power (P) in a circuit is the rate at which energy is absorbed or produced with in a circuit. Electrical power (P) is given by

$$P = \frac{V^2}{R}$$

Here, V = Potential difference

R = Resistance

Hence, $P \propto V^2$

Thus (c) is correct option.

40. If the length of a conductor is halved, then its conductance will be

(a) halved (b) doubled

(c) quadrupled (d) unchanged

Ans : Main 2006

Initial length, $l_1 = l$

Final length, $l_2 = \frac{l}{2}$

conductance of the conductor,

$$\sigma = \frac{A}{\rho l} \propto \frac{1}{l}$$

Therefore, $\frac{\sigma_1}{\sigma_2} = \frac{l_2}{l_1}$

$$= \frac{l/2}{l} = \frac{1}{2}$$

$$\sigma_2 = 2\sigma_1$$

Thus conductance of conductor will be doubled.

Thus (b) is correct option.

41. The current flowing through a lamp, marked as 60 W and 240 V is

(a) 0.25 A (b) 1 A

(c) 2.5 A (d) 5 A

Ans : SQP 2012

Power of lamp, $P = 60$ W

Voltage of lamp, $V = 240$ Volt

Current flowing through the lamp,

$$I = \frac{P}{V}$$

$$= \frac{60}{240} = 0.25\text{ A}$$

Thus (a) is correct option.

42. A battery of 12 V and internal resistance 0.5 Ω is connected across a variable resistance R. The value of R, for which the power delivered is maximum is equal to

(a) 0.25 Ω (b) 0.5 Ω

(c) 1.2 Ω (d) 2.4 Ω

Ans : Main 2016

Voltage of battery, $V = 12$ Volt

Internal resistance, $r = 0.5\,\Omega$

and Variable resistance $= R$

for maximum power, the value of variable resistance is equal to the internal resistance of the battery,

i.e., $R = r = 0.5\,\Omega$

Thus (b) is correct option.

43. Internal resistance of a cell of e.m.f. 12 V is 0.05 Ω. It is connected to an unknown resistance. Voltage across the cell, when a current of 60 A is drawn from it, is

(a) 15 V (b) 12 V

(c) 9 V (d) 6 V

Ans : Comp 2007

E.m.f. of cell, $E = 12$ Volt

Internal resistance of cell, $r = 0.05\,\Omega$

Current drawn from the cell, $I = 60$ A

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Voltage across the cell,

$$V = E - Ir$$
$$= 12 - (60 \times 0.05)$$
$$= 12 - 3$$
$$= 9 \text{ Volt}$$

Thus (c) is correct option.

44. Dimension of electromotive force (e.m.f.) is.

(a) ML^2T^{-2} (b) $ML^2T^{-2}I^{-1}$

(c) MLT^{-2} (d) $ML^2T^{-3}I^{-1}$

Ans : SQP 2016

Electromotive force (emf)

$$= \frac{\text{Work done}(W)}{\text{Charge}(Q)} \quad ...(1)$$

Since, Work = force × displacement

Hence, $Q = [M^1L^1T^{-2}] \times [L]$

$$= [M^1L^2T^{-2}]$$

Charge, $Q = It = [IT]$

From equation (1),we get

$$\text{E.m.f.} = \frac{[M^1L^2T^{-2}]}{[IT]} = [M^1L^2T^{-3}I^{-1}]$$

Thus (d) is correct option.

45. A 100 W, 200 V bulb is connected to a 160 volts supply. The actual power consumption would be

(a) 64 W (b) 80 W

(c) 100 W (d) 125 W

Ans : SQP 2013, 2009

Power of bulb, $P = 100$ W

Voltage of bulb, $V = 200$ Volt

Supply voltage, $V_S = 160$ Volt

resistance of bulb,

$$R = \frac{V^2}{P}$$
$$= \frac{(200)^2}{100} = 400\,\Omega$$

Therefore, actual power consumption,

$$P = \frac{(V_S)^2}{R} = \frac{(160)^2}{400} = 64 \text{ W}$$

Thus (a) is correct option.

46. The drift velocity V_d and applied electric field E of a conductor are related as

(a) $V_d \propto \sqrt{E}$ (b) $V_d \propto E$

(c) $V_d \propto E^2$ (d) $V_d =$ constant

Ans : Main 2005

The relation between drift velocity V_d and electric field $(\vec{E})$ is given by,

$$\vec{V} = \frac{e\vec{E}\tau}{m}$$

where, τ = relaxation time

m = mass of electron

e = charge on electron

Hence, $\vec{V} = \frac{e\vec{E}\tau}{m}$

$$\vec{V_d} \propto \vec{E}$$

Thus (b) is correct option.

47. A current of 10 ampere flows in a wire for 10 sec. If potential difference across the wire is 15 volt, the work done will be

(a) 150 (b) 75 J

(c) 1500 J (d) 750 J

Ans : Main 2012

Current, $I = 10$ ampere

Time, $t = 10$ sec

Potential difference,

$$V = 15 \text{ volt}$$

, $V = \frac{W}{q}$

Hence, $W = Vq = VIt$ [Since, $q = It$]

$$= 15 \times 10 \times 10 = 1500 \text{ J}$$

Thus (c) is correct option.

48. A battery sends a current of 1.5 A through an external resistance of 1.0 Ω. If internal resistance of the battery is 0.5 Ω, its emf is

(a) 2.00 V (b) 2.25 V

(c) 2.50 V (d) 2.75 V

Ans : Main 2022 Sem-I

$$I = 1.5 \text{ A}$$
$$R = 1.0\,\Omega,\ r = 0.5\,\Omega$$
$$\text{emf} = E = ?$$

As we know, $I = \frac{E}{R+r}$

$$E = I(R+r)$$
$$= 1.5(1.0 + 0.5) = 2.25 \text{ V}$$

Thus (b) is correct option.

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49. When a potential difference of 2 V is applied between the two ends of a 1 m long and uniform metallic wire, current density in it is found to be $4 \times 10^6\ \text{Am}^{-2}$. Resistivity of the material of the wire is

(a) $5 \times 10^{-7}\ \Omega$-m (b) $5 \times 10^{-8}\ \Omega$-m

(c) $5 \times 10^{6}\ \Omega$-m (d) $5 \times 10^{8}\ \Omega$-m

Ans : Main 2022 Sem-I

Given,

$$J = 4 \times 10^6\ \text{Am}^{-2},\ l = 1\ \text{m},\ V = 2\ \text{Volt}$$

$$J = \frac{i}{A} = \frac{1}{A}\left(\frac{V}{R}\right) = \frac{V}{A} \cdot \frac{A}{\rho l} = \frac{V}{\rho l}$$

$\rho =$ resistivity

$$= \frac{V}{Jl} = \frac{2}{4 \times 10^6 \times 1}$$

$$= 5 \times 10^{-7}\ \Omega - \text{m}$$

Thus (a) is correct option.

50. If R_1 and R_2 are filament's resistances of a 200 W and a 100 W bulb respectively, designed to operate on the same voltage, then

(a) $R_1 = R_2$ (b) $R_2 = 2R_1$

(c) $R_2 = 4R_1$ (d) $R_1 = 4R_2$

Ans : Main 2014

$$P = \frac{V^2}{R}$$

$$P_1 = \frac{V_1^2}{R_1} = \frac{V^2}{R_1}$$

[let common voltage be V] ...(1)

$$P_2 = \frac{V_2^2}{R_2} = \frac{V^2}{R_2}$$

From Eqs. (1) and (2), we get

$$P_1 R_1 = P_2 R_2$$

$$200 \times R_1 = 100 \times R_2$$

$$R_2 = 2R_1$$

Thus (b) is correct option.

51. Ohm's law in vector form is

(a) $V = IR$ (b) $\vec{J} = \sigma \vec{E}$

(c) $\vec{J} = \rho \vec{E}$ (d) $\vec{E} = \sigma \vec{J}$

Ans : SQP 2018

As we know,

$$I = Anev_d$$

$$I = nAe\left(\frac{eE\tau}{m}\right) \qquad \left[v_d = \frac{eE\tau}{m}\right]$$

$$I = \frac{nAe^2\tau E}{m}$$

$$\frac{I}{A} = \frac{ne^2\tau E}{m}$$

$$\vec{J} = \frac{ne^2\tau \vec{E}}{m} \qquad \left[J = \frac{I}{A}\right]$$

$$\vec{J} = \left(\frac{1}{\rho}\right)\vec{E} \qquad \left[\rho = \frac{m}{ne^2\tau}\right]$$

$$\vec{J} = \sigma \vec{E} \qquad \left[\sigma = \frac{1}{\rho}\right]$$

Thus (b) is correct option.

52. N identical cells each of emf e and internal resistance r are connected in series to form a row. M such rows are connected in parallel to form a battery. When an external resistance R is connected to the battery, current flowing through it is

(a) $MNe/(R + r)$

(b) $MNe/(NR + Mr)$

(c) $MNe/(MR + Nr)$

(d) $Ne/(MR + Nr)$

Ans : Main 2022 Sem-I

$$E_{eq} = Ne$$

$$\frac{1}{r_{eq}} = \frac{1}{Nr} + \frac{1}{Nr} \ldots + \text{upto } M \text{ terms} = \frac{M}{Nr}$$

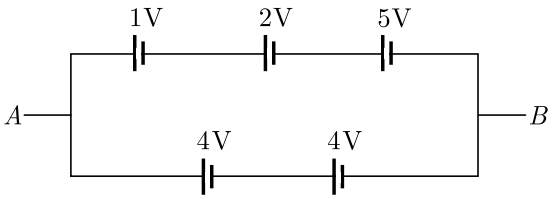
$$r_{eq} = \frac{Nr}{M}$$

$$I = \frac{E_{eq}}{r_{eq} + R} = \frac{Ne}{\frac{Nr}{M} + R}$$

$$= \frac{MNe}{MR + Nr}$$

Thus (c) is correct option.

53. Figure below shows five DC sources (cells). Their emfs are shown in the figure.



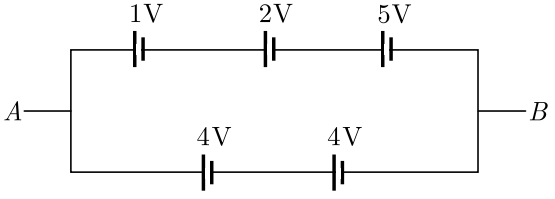
Emf of the battery AB is

(a) 8 V (b) 16 V

(c) 4 V (d) 2 V

Ans : Main 2012

Consider the diagram



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The cells connected in series will be added up for the calculation of equivalent emf.

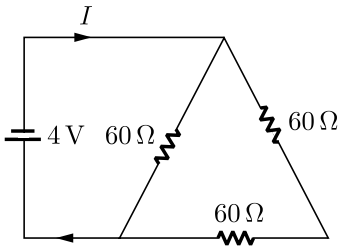
Now, the two cells are in parallel.

So, the equivalent emf will be

V_e = emf of each cell = 8 V.

Thus (a) is correct option.

54. The current in the circuit shown in figure below, will be



(a) (1/45) A (b) (1/15) A

(c) (1/10) A (d) (1/5) A

Ans : Main 2022 Semi

$$R_s = 60 = 60 = 120\,\Omega$$

R_s and R_3 are in parallel.

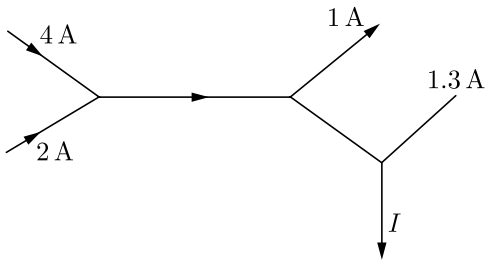
$$R_{eq} = \frac{R_s R_3}{R_s + R_3} = \frac{120 \times 60}{120 + 60}$$

$$= \frac{120 \times 60}{180} = 40\,\Omega$$

$$i = \frac{V}{R} = \frac{4}{40} = \frac{1}{10}\text{ A}$$

Thus (c) is correct option.

55. The figure given below currents in a part of an electric circuit. The current i is



(a) 1.7 A (b) 3.7 A

(c) 2.7 A (d) 4.7 A

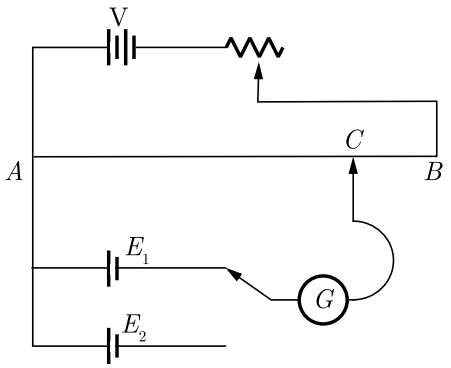
Ans : Main 2022 Sem-I

According to the KCL ,we get

$$I = 4 + 2 - 1 - 13 = 3.7\text{ A}$$

Thus (b) is correct option.

56. The circuit shown in figure below is used to compare the emf of two cells E_1 and E_2 where $E_2 > E_1$. The null point is at C when the galvanometer is connected to E_1. When the galvanometer is connected to E_2, the null point will be



(a) to the left of C (b) to the right of C

(c) at C itself (d) no where on AB

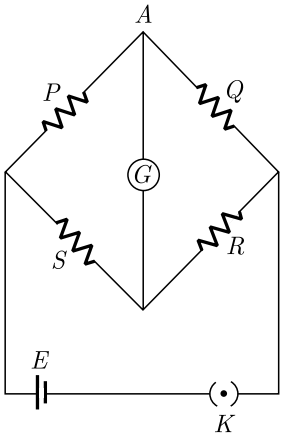
Ans : Main 2022 Sem-I

The left of C since $E \propto I$. So, for $E_1 > E_2$.

We have $I_1 > I_2$ and hence null point will be obtained at shorter length i.e., to the left of C.

Thus (a) is correct option.

57. In the Wheatstone bridge circuit shown below, $P = 10\,\Omega$, $Q = 20\,\Omega$, $R = 200\,\Omega$, $S = 100\,\Omega$ and emf of the battery being 2 V. The current flowing through the galvanometer is the wire is



(a) 0 (b) 1 A

(c) 2 A (d) 3 A

Ans : Main 2022 Sem-I

$$P = 10\,\Omega,\ Q = 20\,\Omega$$

$$S = 100\,\Omega,\ R = 200\,\Omega$$

As $\frac{P}{Q} = \frac{10}{20} = \frac{1}{2}$, $\frac{S}{R} = \frac{100}{200} = \frac{1}{2}$

$$\frac{P}{Q} = \frac{S}{R}$$

Here, it is a balanced Wheatstone bridge.

I_g = current through galvanometer = 0

Thus (a) is correct option.

58. If a current of 300 mA is flowing in a conductor, then the number of electrons passed through the conductor in 4 min is (Charge on an electron $= 1.6 \times 10^{-19}$ C)

(a) 4.5×10^{20} (b) 9.0×10^{20}

(c) 4.5×10^{18} (d) 9.0×10^{18}

Ans : **Main 2015**

Current, $I = 300\,\text{mA} = 0.3\,\text{A}$

Time, $t = 4\,\text{min} = 240\,\text{s}$

And charge on an electron,

$$e = 1.6 \times 10^{-19}\,\text{C}$$

charge passing through a conductor,

$$q = I \times t$$

$$= 0.3 \times 240 = 72\,\text{C}$$

Therefore number of electrons passed through the conductor,

$$n = \frac{q}{e} = \frac{72}{1.6 \times 10^{-19}}$$

$$= 4.5 \times 10^{20}$$

Thus (a) is correct option.

59. The power of electric circuit is

(a) VR (b) V^2R

(c) $\frac{V^2}{R}$ (d) V^2RI

Ans : **Main 2015**

Electric power, $P = \frac{W}{t}$

Here, $W = VIt$

$$P = \frac{VIt}{t}$$

$$P = VI \quad ...(1)$$

According to the ohm's law

$$V = IR$$

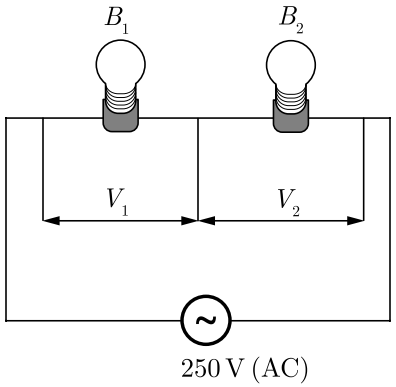
$$I = \frac{V}{R} \quad ...(2)$$

From equation (1), we get

$$P = V \times \frac{V}{R} = \frac{V^2}{R}$$

Thus (c) is correct option.

60. Two bulbs B_1 and B_2 are connected in series with a source of emf 250 V as shown in the figure below. The labels on the bulbs read 250 V, 80 W and 250 V, 100 W respectively.



(i) What will be the ratio of the resistance of the bulbs R_1/R_2?

(a) 5 : 4 (b) 4 : 5

(c) 1 : 1 (d) 5 : 3

(ii) What will be the ratio of the power consumed (P_1/P_2) when connected in series?

(a) 5 : 4 (b) 4 : 5

(c) 1 : 1 (d) 5 : 3

(iii) What is the ratio of the pd across the bulbs (V_1/V_2) ?

(a) 5 : 4 (b) 4 : 5

(c) 1 : 1 (d) 5 : 3

Ans : **Main 2022 Sem I**

(i) (a) 5 : 4

$$R_1 = \frac{(250)^2}{80},\ R_2 = \frac{(250)^2}{100}$$

$$\frac{R_1}{R_2} = \frac{\frac{(250)^2}{80}}{\frac{(250)^2}{100}} = \frac{100}{80} = 5:4$$

(ii) (a) 5 : 4

$$\frac{P_1}{P_2} = \frac{I^2R_1}{I^2R_2} = \frac{R_1}{R_2} = 5:4$$

(iii) (a) 5 : 4

$$\frac{V_1}{V_2} = \frac{IR_1}{IR_2} = 5:4$$

61. The voltage V and current I graphs for a conductor at two different temperatures T_1 and T_2 are shown in the figure. The relation between T_1 and T_2 is

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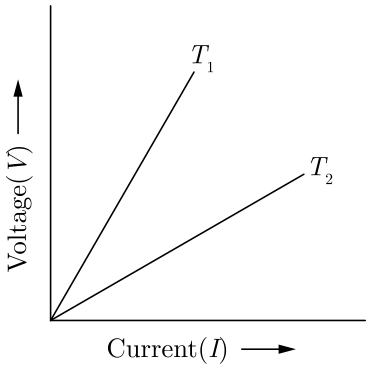


(a) $T_1 > T_2$ (b) $T_1 \approx T_2$

(c) $T_1 = T_2$ (d) $T_1 < T_2$

Ans : **Main 2014**

We know from the Ohm's law that resistance of a conductor,

$$R = \frac{V}{I}$$

We also know from given figure that $\frac{V}{I}$ is the slope of the $V-I$ graph.

Since, $\left(\frac{V}{I}\right)_1 > \left(\frac{V}{I}\right)_2$

Therefore, $R_1 > R_2$ ...(1)

We also know that the resistance at a temperature T,

$$R = R_0(1+\alpha T)$$

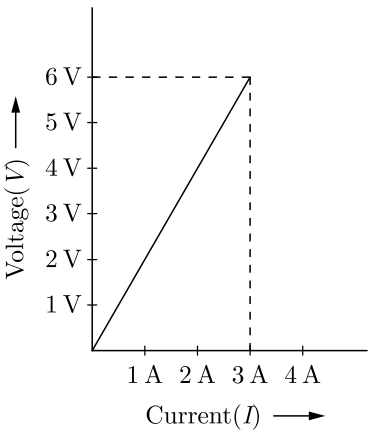
or, $R \propto T$ ...(2)

From equation (1) and (2), we get

$$T_1 > T_2$$

Thus (a) is correct option.

62. The variation of voltage V and current I in a conductor is given below. The resistance of the conductor is



(a) 1 Ω (b) 2 Ω

(c) 3 Ω (d) 4 Ω

Ans : **Main 2011**

$V-I$ graph for the given conductor is a straight line. Thus it obeys Ohm's law.

We find from the given graph that voltage is 6 V, when current in the conductor is 3 A.

Therefore, resistance of conductor,

$$R = \frac{V}{I} = \frac{6}{3} = 2\,\Omega$$

Thus (b) is correct option.

63. The electric resistance of a certain wire of iron is R. If its length and radius are both doubled, then its

(a) both resistance and specific resistance will remain unchanged.

(b) resistance will be doubled and specific resistance will be halved.

(c) resistance will be halved and specific resistance will be doubled.

(d) resistance will be halved and specific resistance will remain unchanged.

Ans : **Main 2013, 2011**

Initial resistance, $R_1 = R$

Final length of wire, $l_2 = 2l_1$

Final radius of wire, $r_2 = 2r_1$

Resistance of the wire of iron,

$$R = \rho\frac{l}{A} = \rho\frac{l}{\pi r^2} \propto \frac{l}{r^2}$$

Therefore, $\frac{R_1}{R_2} = \frac{l_1}{l_2} \times \left(\frac{r_2}{r_1}\right)^2$

Here, l_1 = initial length of wire

R_2 = final resistance of the wire of iron

r_1 = initial radius of wire

$$= \frac{l_1}{2l_1} \times \left(\frac{2r_1}{r_1}\right)^2$$

$$= \frac{1}{2} \times 4 = 2$$

$$R_2 = \frac{R_1}{2} = \frac{R}{2}$$

We also know that specific resistance of a wire depends upon nature of the material of wire and is independent of the dimensions of the wire. Therefore specific resistance of the wire remain unchanged.

Thus (d) is correct option.

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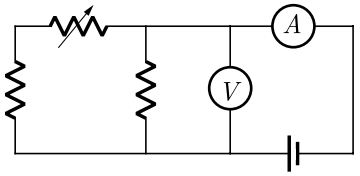
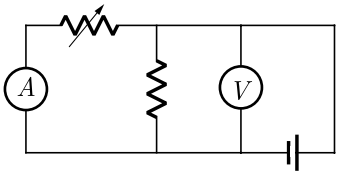
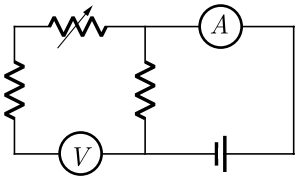
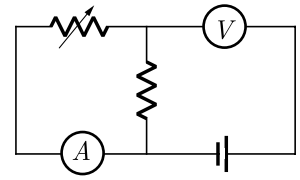
64. Which of the following set up can be used to verify the Ohm's law?

(a)


(b)


(c)


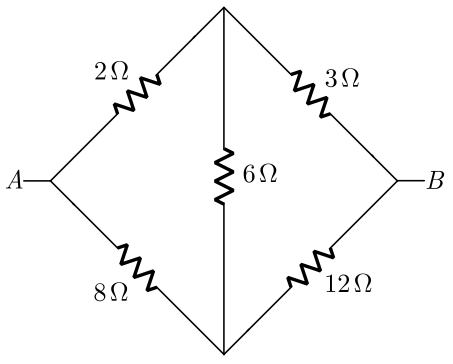
(d)


Ans : **Main 2012**

Ohm's law gives the resistance offered by a conductor by measuring steady current I flowing through the conductor and voltage drop across the ends of the conductor.

We also know that ammeter is always connected in series with the cell to measure current flowing through the conductor and voltmeter is always connected in parallel to the cell to measure voltage drop across the conductor. Therefore, option (a) is used to verify the Ohm's law. Thus (a) is correct option.

65. Five resistors are connected as shown in the figure.



The effective resistance i.e., equivalent resistance between the points A and B is

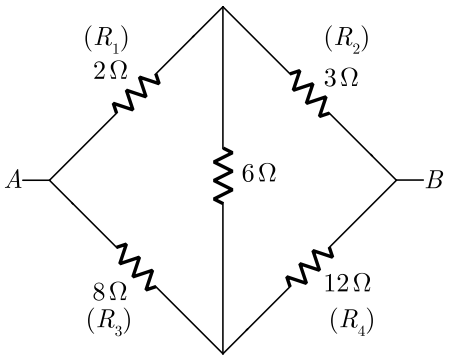
(a) $4\,\Omega$ (b) $5\,\Omega$

(c) $15\,\Omega$ (d) $20\,\Omega$

Ans : **Main 2013**

The given combination will act as balanced Wheatstone bridge. The resistance of the middle branch can be removed.

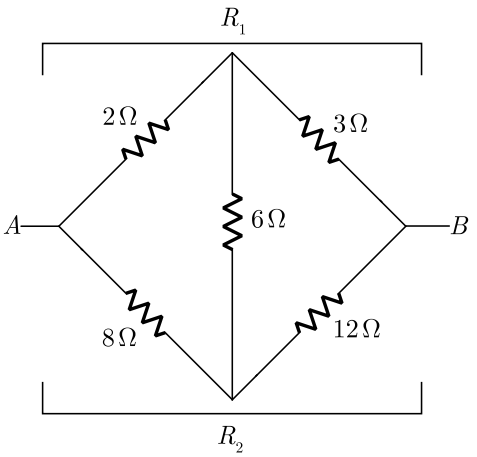
Clearly,



$$R_1R_4 = (2\,\Omega)(12\,\Omega) = 24\,\Omega$$

$$R_2R_3 = (3\,\Omega)(8\,\Omega) = 24\,\Omega$$

$R_1R_4 = R_2R_3$ hence bridge is balanced



$$R_1 = 5\,\Omega,\ R_2 = 20\,\Omega$$

$$R_{eq} = \frac{R_1R_2}{R_1 + R_2} = \frac{5 \times 20}{25}$$

$$= \frac{100}{25} = 4\,\Omega$$

Thus (a) is correct option.

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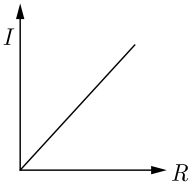
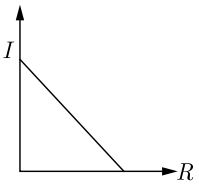
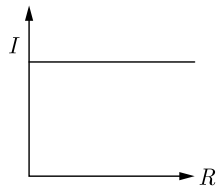
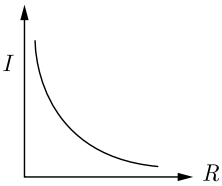
66. If a variable resistance is connected to a cell of constant emf, then the graph which represents the correct relationship between current I and resistance R is

(a) 

(b) 

(c) 

(d) 

Ans : **Main 2022 Sem-I**

According to the Ohm's law, $V = IR$

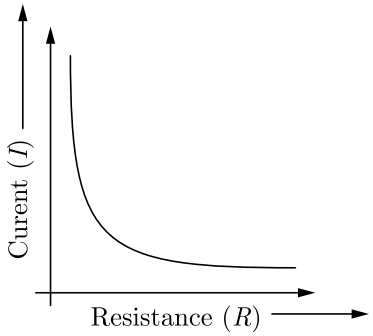
Now, if V = constant

So, $I \propto \frac{1}{R}$

where, I = current

and R = variable resistance

The variation is shown in the graph.



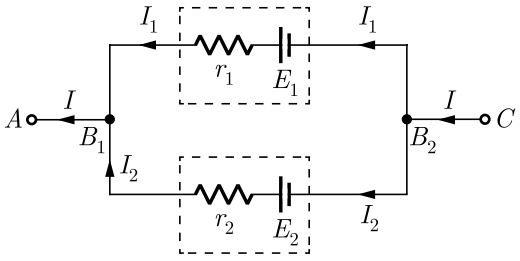
67. Two cells of emf ε_1 and ε_2, internal resistance r_1 and r_2, connected in parallel. The equivalent emf of the combination is

(a) $\frac{\varepsilon_1 r_1 + \varepsilon_2 r_2}{r_1 + r_2}$ (b) $\frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2}$

(c) $\sqrt{\varepsilon_1 \times \varepsilon_2}$ (d) $\frac{\varepsilon_1 + \varepsilon_2}{2}$

Ans : **Main 2017**

According to the question,



Potential difference between the terminal of first cell,

$$V = V_{B_1} - V_{B_2} = \varepsilon_1 - I_1 r_1$$

$$I_1 = \frac{\varepsilon_1 - V}{r_1} \quad ...(1)$$

Similarly, $$I_2 = \frac{\varepsilon_2 - V}{r_2} \quad ...(2)$$

$$I = I_1 + I_2$$

$$= \frac{\varepsilon_1 - V}{r_1} + \frac{\varepsilon_2 - V}{r_2}$$

$$= \left(\frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2}\right) - V\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$

$$I = \left(\frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2}\right) - V\left(\frac{r_1 + r_2}{r_1 r_2}\right)$$

$$V\left(\frac{r_1 + r_2}{r_1 r_2}\right) = \frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 r_2} - I$$

$$V = \frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2} - I\frac{r_1 r_2}{r_1 + r_2} \quad ...(1)$$

$$V = E_{eq} - I r_{eq} \quad ...(2)$$

After comparing equation. (1) and (2), we get

$$E_{eq} = \frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2}$$

Thus (b) is correct option.

68. The circuit diagram given below is that of a potentiometer used to measure internal resistance r of a cell.

(i) To find out the first balancing length l_1,

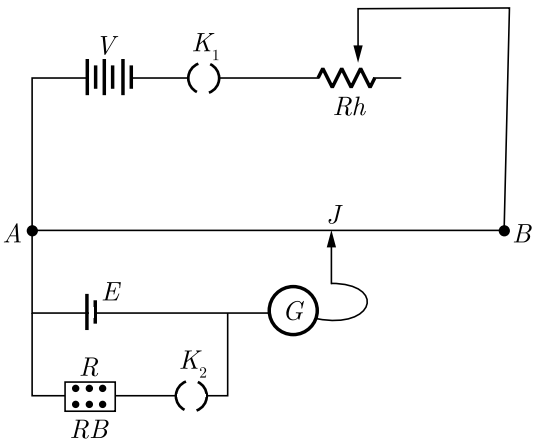
(a) both the keys K_1 and K_2 are closed together.

(b) both the keys K_1 and K_2 are kept open.

(c) K_1 is closed and K_2 is kept open.

(d) K_2 is closed and K_1 is kept open.

(ii) Working formula to calculate the internal resistance of a cell is



95. Why is a potentiometer preferred over a voltmeter in measuring the emf of a cell?

Ans : **Main 2007**

Potentiometer works on the principle of null deflection and it does not draw any current from the cell whose actual emf is to be measured whereas voltmeter measures the potential difference, because it draws some current from the cell. So, potentiometer is preferred over voltmeter.

96. Define temperature coefficient of resistance of the material of a conductor.

Ans : **Main 2014**

Change in resistance per unit original resistance per unit rise in temperature is called temperature coefficient of resistance.

i.e. $$\alpha = \frac{R_2 - R_1}{R_1(t_2 - t_1)}$$

R_1, R_2 are resistances at $t_1\,^\circ\text{C}$, $t_2\,^\circ\text{C}$

97. Define the current sensitivity of a galvanometer. Write its SI unit.

Ans : **Main 2017**

Ratio of deflection produced in the galvanometer and the current flowing through it is called current sensitivity.

Current sensitivity, $$S_i = \frac{\theta}{I}$$

SI unit of current sensitivity S_i is division/ampere or radian/ampere.

98. Alloys of metals have greater resistivity than their constituent metals. Why?

Ans : **Main 2006**

In an alloy, like nichrome (Ni – Cr alloy), Ni^{2+} and Cr^{3+} ions occupy random locations relative to each other. An electron, therefore, passes through a very random medium and is very frequently deflected. So there is a small relaxation time and hence large resistivity. In general, alloys have more resistivity than that of their constituent metals.

99. Does the emf represent a force of potential energy or work done per unit charge or potential difference? Does emf have electrostatic origin?

Ans : **SQP 2020, 2017**

The term emf is a misnomer. Literally, emf means the force that pushes the electrons in a circuit. Since emf does not have simple electrostatic origin, so the concept of potential is not strictly applicable. It has the nature of work done per unit charge and that of force. independent of its size or shape.

100. Define conductivity of a material. Give its SI unit.

Ans : **SQP 2010**

The reciprocal of the resistivity of a material is called its conductivity and is denoted by σ. Thus,

$$\text{Conductivity} = \frac{1}{\text{Resistivity}}$$

or $$\sigma = \frac{1}{\rho}$$

The SI unit of conductivity is $\text{ohm}^{-1}\text{m}^{-1}$ or ohm m^{-1} or Sm^{-1}.

101. Define potential gradient. Give its units.

Ans : **Main 2024, 2015**

The potential drop unit length of the potentiometer wire is known as potential gradient. It is given by

$$k = \frac{V}{l}$$

$$\text{SI unit of potential gradient} = \text{Vm}^{-1}$$

$$\text{Practical unit of potential gradient} = \text{V cm}^{-1}$$

102. How will be the sensitivity of a potentiometer change with increase in current flowing through its wire?

Ans : **Main SQP 2018**

Sensitivity of potentiometer means smallest potential difference that can be measured with the help of it. It can be increased by decreasing its potential gradient (K) i.e. sensitivity $\propto \frac{1}{K}$

By increasing the current through the wire, sensitivity of the potentiometer decreases.

103. In case of metals, what is the relation between current density (J), electrical conductivity (σ) and electric field intensity (E)?

Ans : **Main 2023**

$$I = nAev_d = nAe\left(\frac{eE}{m}\tau\right)$$

$$\frac{I}{A} = \frac{ne^2\tau E}{m}$$

$$J = \frac{1}{\rho}E \qquad \left[J = \frac{I}{A} \text{ and } \rho = \frac{m}{ne^2T}\right]$$

$$J = \sigma E$$

104. State the physical condition in which Ohm's law is not valid for a conductor.

Ans : **Main 2002**

Ohm's law is

$$V = RI$$

where, R is resistance of the conductor which is constant at a given temperature

$$V \propto I$$

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(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **Comp 2007**

The electric power of a heater is more than that of a bulb. As $P \propto \frac{1}{R}$, the resistance of heater is less than that of the electric bulb. When a heater connected in parallel to the bulb is switched on, it draws more current due to its lesser resistance, consequently, the current through the bulb decreases and so it becomes dim.

When the heater coil becomes sufficient hot, its resistance becomes more and hence it draws a little lesser current. Consequently the current through the electric bulb recovers.

Thus (b) is correct option.

72. **Assertion :** The electric bulbs glows immediately when switch is on.

Reason : The drift velocity of electrons in a metallic wire is very high.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **Main 2014**

In a conductor there are large number of free electrons. When we close the circuit, the electric field is established instantly with the speed of electromagnetic wave which cause electron drift at every portion of the circuit. Due to which the current is set up in the entire circuit instantly. The current which is set up does not wait for the electrons flow from one end of the conductor to the another end. It is due to this reason, the electric bulb glows immediately when switch is on.

Thus (c) is correct option.

73. **Assertion :** In a simple battery circuit, the point of the lowest potential is negative terminal of the battery.

Reason : The current flows towards the point of the higher potential, as it does in such a circuit from the negative to the positive terminal.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **Main 2017, 2015**

Positive terminal of a battery is point of highest potential and current flows from highest to lowest potential i.e. from positive to negative potential.

Thus (c) is correct option.

74. **Assertion :** Long distance power transmission is done at high voltage.

Reason : At high voltage supply power losses are less.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **SQP 2014**

$$\text{Power loss} = i^2R = \left(\frac{P}{V}\right)^2 R$$

$[P = \text{Transmitted power}]$

Thus (a) is correct option.

75. **Assertion :** The current density $\vec{J}$ at any point in ohmic resistor is in direction of electric field $\vec{E}$ at the point.

Reason : A point charge when released from rest in a region having only electrostatic field always moves along electric lines of force.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **Main 2014**

From relation $\vec{J} = \sigma\vec{E}$, the current density $\vec{J}$ at any point in ohmic resistor is in direction of electric field $\vec{E}$ at that point. In space having non-uniform electric field, charges released from rest may not move along ELOF. Hence Assertion is correct while Reason is incorrect.

Thus (c) is correct option.

NODIA

125. Why alloys like constantan or manganin are used for making standard resistors?

Ans : **Main 2017**

Use of alloys like constantan or manganin in making standard resistance coils. This is because of the following reasons :

1. These alloys have high value of resistivity.
2. They have very small temperature coefficient. So their resistance does not change appreciably even for several degrees rise of temperature.
3. They are least affected by atmospheric conditions like air, moisture, etc.
4. Their contact potential with copper is small.

126. Write the expression for the resistivity of the conductor and explain each term of the expression.

Ans : **SQP 2011**

The resistances of conductor is directly proportional to the length l of the conductor and inversely proportional to the area of the cross-section, A of the conductor i.e.,

$$R \propto \frac{l}{A}$$

$$R = \frac{\rho l}{A}$$

$$\rho = \frac{RA}{l}$$

where, ρ = resistivity of conductor

R = resistance of conductor

127. What do you mean by sensitivity of a Wheatstone bridge? On what factors does it depend?

Ans : **SQP 2017**

A Wheatstone bridge is said to be sensitive if it shows a large deflection in the galvanometer for a small change of resistance in the resistance arm.

The sensitivity of the Wheatstone bridge depends on two factors:

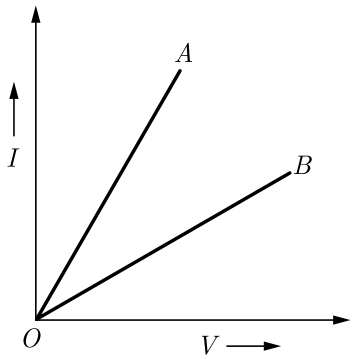
1. Relative magnitudes of the resistances in the four arms of the bridge. The bridge is most sensitive when all the four resistances are of the same order.
2. Relative positions of battery and galvanometer.

128. Define the term resistance. Give physical explanation of the opposition by a conductor to the flow of current through it.

Ans : **SQP 2015**

Resistance of a conductor is the property by virtue of which it opposes the flow of current through it. Collisions are the basic cause of resistance. When a potential difference is applied across a conductor, its free electrons get accelerated. On their way, they frequently collide with the positive metal ions i.e., their motion is opposed and this opposition to the flow of electrons is called resistance. Larger the number of collisions per second, smaller is the relaxation time τ, and larger will be the resistivity ($\rho = m/ne^2\tau$).

129. V - I graph for two identical conductors of different materials A and B is shown in the figure. Which one of the two has higher resistivity?



Ans : **SQP 2024, 2007**

The resistivity of material B is higher.

Reason : If the same amount of the current flows through them, then $V_B > V_A$ and from Ohm's law $R_B > R_A$. Hence, the resistivity of the material B is higher.

130. How can we classify solids on the basis of their resistivity values?

Ans : **SQP 2018**

On the basis of their resistivity values, solids can be classified into following three categories :

1. **Conductors :** Metals have low resistivities in the range of $10^{-8}\,\Omega$m to $10^{-6}\,\Omega$m. These are known as good conductors of electricity.
2. **Insulators :** These are the substances which have large resistivities, more than $10^4\,\Omega$m. Insulators like glass and rubber have resistivities in the range 10^{14} to $10^{16}\,\Omega$m.
3. **Semiconductors :** These are the substances having resistivities between those of conductors and insulators i.e., between $10^{-6}\,\Omega$m to $10^4\,\Omega$m. Germanium and silicon are typical semiconductors.

131. A potential difference of V volt is applied across a copper wire of length l and diameter d. How will the drift velocity be affected, if

(i) V is doubled.

(ii) l is doubled.

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ONE MARK QUESTIONS

81. How does the random motion of free electrons in a conductor get affected when a potential difference is applied across the ends?

Ans : **Main 2019**

They start drifting in the same direction.

82. The charging current for a capacitor is 0.25 A. What is the displacement current across its plates?

Ans : **SQP 2019**

The displacement current is equal to the charging current. So, displacement current is 0.25 A.

83. Define the term 'relaxation time' in a conductor

Ans : **Main 2016**

The average time between successive collisions of electrons in a conductor is known as relaxation time.

84. Two wires one of copper and other of manganin have same resistance and equal length. Which wire is thicker and why?

Ans : **Main 2014**

Manganin wire is thicker because $R = \frac{\rho l}{A}$.

As ρ increases, R also increases.

85. Write the expression for the drift velocity of charge carriers in a conductor of length L across which a potential difference V is applied.

Ans : **SQP 2017, 2015**

Drift velocity, $v_d = \frac{eV}{mL}\tau$

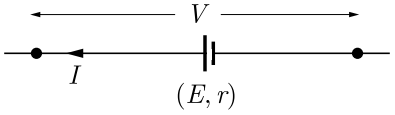
86. How does drift velocity of electrons in a metallic conductor vary with increase in temperature? Explain.

Ans :

When temperature increases, the collisions of electrons occur more frequently, so relaxation time decreases and hence, drift velocity decreases.

87. A cell of emf E and internal resistance r draws a current I. Write the relation between terminal voltage V in terms of E, I and r.

Ans : **SQP 2009**



The terminal voltage $V < E$, so $V = E - Ir$

88. A resistance R is connected across a cell of emf E and internal resistance r. A potentiometer now measures the potential difference between the terminals of the cell as V. Write the expression for r in terms of E, V and R.

Ans : **Main 2011**

$$r = \left(\frac{E}{V} - I\right)R$$

89. Nichrome and Copper wires of same length and same radius are connected in series. Current/ is passed through them. Which wire gets heated up more? Justify your answer.

Ans : **SQP 2017**

Nichrome, since its resistance is high.

90. Name the two conservation laws implied in Kirchhoff's laws for electric circuits.

Ans : **Main 2017, 2007, 2002**

Kirchhoff's first law is based on conservation of charge and second law is based on conservation of energy.

91. The emf of a cell is always greater than its terminal voltage. Why? Give reason.

Ans : **Comp 2025, 2018**

The emf of a cell is greater than its terminal voltage because there is some potential drop across the cell due to its small internal resistance.

92. Why is internal resistance of a secondary cell low?

Ans : **SQP 2009**

The secondary cell with provide higher value of maximum current so the value of internal resistance of secondary cell is lower than primary cell.

93. For a metallic conductor, what is the relation between current density (J), conductivity (σ) and electric field intensity (E)?

Ans : **Main 2016**

For a metallic conductor, the relation between current density (J), conductivity (σ) and electric field intensity (E) can be given as $\vec{J} = \sigma\vec{E}$

94. Explain the statement 'temperature coefficient of resistance of metal is $4 \times 10^{-3}/^{\circ}\text{C}$.

Ans : **Main 2010.**

As given temperature coefficient of resistance of a metal is $4 \times 10^{-3}/^{\circ}\text{C}$, it represents the increase in resistance by $4 \times 10^{-3}\,\Omega$ for rise of temperature by unit degree Celsius. (1°C)

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76. **Assertion :** Bending a wire does not effect electrical resistance.

Reason : Resistance of wire is proportional of resistivity of material.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **SQP 2006**

Resistance wire $R = \frac{\rho l}{A}$, where ρ is resistivity of material which does not depend on the geometry of wire. Since when wire is bent resistivity, length and area of cross-section do not change, therefore resistance of wire also remain same.

Thus (a) is correct option.

77. **Assertion :** In a simple battery circuit, the point of the lowest potential is positive terminal of the battery.

Reason : The current flows towards the point of the higher potential, as it does in such a circuit from the negative to the positive terminal.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **SQP 2003**

Positive terminal of the battery is point of highest potential and current flows from highest to lowest potential i.e. from positive to negative potential.

Thus (d) is correct option.

78. **Assertion :** Kirchhoff's junction rule follows from conservation of charge.

Reason : Kirchhoff's loop rule follows from conservation of momentum.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **Main 2009**

Kirchhoff's loop rule follows from conservation of energy. Thus (c) is correct option.

79. **Assertion :** When current through a bulb decreases by 0.5%, the glow of bulb decreases by 1%.

Reason : Glow (Power) which is directly proportional to square of current.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **SQP 2005**

$$\text{Glow} = \text{Power } (P) = I^2 R$$

Hence, $$\frac{dP}{P} = 2\left(\frac{dI}{I}\right) = 2 \times 0.5 = 1\%$$

Thus (a) is correct option.

80. **Assertion :** Free electrons always keep on moving in a conductor even then no magnetic force act on them in magnetic field unless a current is passed through it.

Reason : The average velocity of free electron is zero.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **Main 2004**

In the absence of the electric current, the free electrons in a conductor are in a state of random motion, like molecule in a gas. Their average velocity is zero. i.e. they do not have any net velocity in a direction. As a result, there is no net magnetic force on the free electrons in the magnetic field. On passing the current, the free electrons acquire drift velocity in a definite direction, hence magnetic force acts on them, unless the field has no perpendicular component.

Thus (a) is correct option.

NODIA

But when temperature changes, R changes, so potential difference (V) will not be proportional to the current (I), thus Ohm's law is not valid in this case.

105. A wire of resistivity ρ is stretched uniformly, so that its length becomes four times. What is its new resistivity? (assume temperature of the wire remains constant during stretching of the wire.)

Ans : **Main 2008**

Resistivity, $\rho = \frac{m}{ne^2\tau}$

where, n = number of electrons = constant

e = electron charge = constant

τ = relaxation time = constant

m = mass of electron = constant

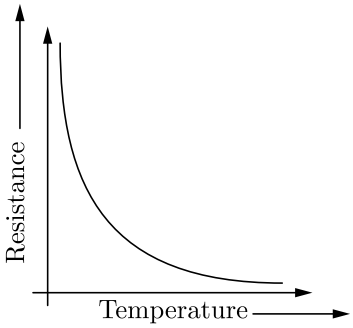
ρ is independent of dimension

So, resistivity remains unchanged when the wire is stretched.

106. Show graphically how electrical resistance of a piece of silicon or germanium varies when its temperature is varied.

Ans : **Main 2008**

While temperature increases, resistance of semiconductor decreases as shown below.



107. A resistor R is connected to a cell of emf e and internal resistance r. Potential difference across the resistor R is found to be V. State the relation between e, V, R and r.

Ans : **Main 2015**

The relation between e, V, R and r is that $e = IR + Ir$

where,

e = emf of cell,

IR = potential drop across external resistance R

Ir = potential drop across internal resistance r.

108. Define electric current.

Ans : **Main 2015**

The flow of electric charges through a conductor constitutes electric current. Quantitatively, electric current across an area held perpendicular to the direction of flow of charge is defined as the amount of charge across that area per unit time.

For a steady flow of charge,

$$I = \frac{Q}{t}$$

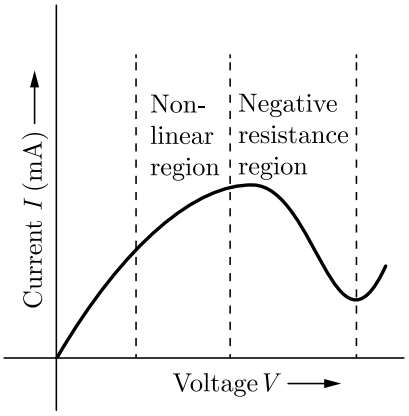
If the rate of flow of charge varies with time,

Then, $$I = \lim_{\Delta t \to 0} \frac{\Delta Q}{\Delta t} = \frac{dQ}{dt}$$

109. Plot a graph showing variation of current versus voltage for the material GaAs.

Ans : **Main 2024, 2020**

The variation of electric current with applied voltage for GaAs is as shown.



110. What is electromotive force?

Ans : **Main 2017**

The emf of a source may be defined as the work done by the source in taking a unit positive charge from its lower potential terminal to the higher potential terminal. Or, it is the energy supplied by the source in taking a unit positive charge once round the complete circuit. It is equal to the terminal potential difference measured in open circuit.

$$\text{E.m.f.} = \frac{\text{Work done}}{\text{Charge}}$$

or $$e = \frac{W}{q}$$

111. What is meant by drift speed of free electrons?

Ans : **Main 2017**

It is defined as the average velocity with which the free electrons in a conductor get drifted towards the positive end of the conductor under

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(a) $r = R\left(\frac{l_1}{l_2} - 1\right)$ (b) $r = R\left(\frac{l_2}{l_1} - 1\right)$

(c) $R = r\left(\frac{l_2}{l_1} - 1\right)$ (d) $R = r\left(\frac{l_1}{l_2} - 1\right)$

(iii) If the value of R is increased, balancing length

(a) l_1 increases

(b) l_2 increases

(c) l_2 decreases

(d) l_2 remains unchanged

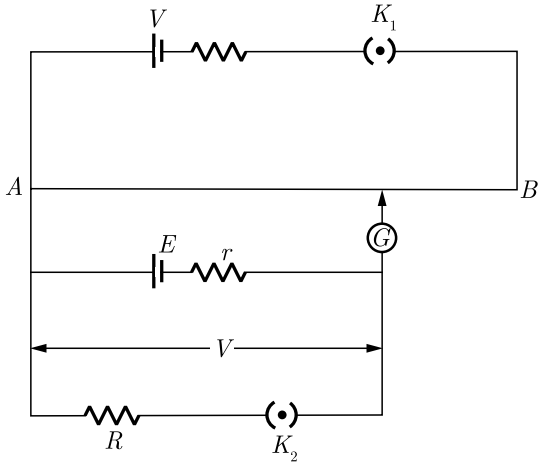
Ans : **Main 2022 Sem-I**

(i) (c) K_1 is closed and K_2 is kept open

(ii) (a) $r = R\left(\frac{l_1}{l_2} - 1\right)$

Length of wire $= l$

At balance point, when K_2 is open, $E = kl_1$



When K_2 is closed,

$$V' = IR = E - Ir = kl_2$$

$$Ir = E - V'$$

$$\frac{V'}{R} \cdot r = E - V'$$

$$r = (E - V') \cdot \frac{R}{V'}$$

$$= \left(\frac{E}{V'} - 1\right) \cdot R$$

As, $\frac{E}{V} = \frac{kl_1}{kl_2} = \frac{l_1}{l_2}$

$$r = (E - V') \cdot \frac{R}{V'}$$

$$= \left(\frac{E}{V'} - 1\right) \cdot R$$

As, $\frac{E}{V} = \frac{kl_1}{kl_2} = \frac{l_1}{l_2}$

$$r = \left(\frac{l_1}{l_2} - 1\right) \cdot R$$

(iii) (b) l_2 increases

ASSERTION AND REASON

69. **Assertion :** Voltmeter is connected in parallel with the circuit.

Reason : Resistance of a voltmeter is very large.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **SQP 2003**

Voltmeter is a galvanometer with high resistance. It measures potential drop across any part of an electrical circuit. It is connected in parallel so that it does not draw any current itself (due to high resistance) and does not affect net resistance of the circuit.

Thus (b) is correct option.

70. **Assertion :** Ohm's law is applicable for all conducting elements.

Reason : Ohm's law is a fundamental law.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **Main 2004**

A conducting device obeys ohm's law when the resistance of device is independent of the magnitude and polarity of the applied potential difference which happens in metallic conductors. Reason is false as ohm's law is not true for non-ohmic conductors such as junction diodes etc.

Thus (c) is correct option.

71. **Assertion :** An electric bulb becomes dim, when the electric heater in parallel circuit is switched on.

Reason : Dimness decreases after sometime.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

NODIA

116. Define electrical conductivity of a conductor and give its SI unit.

Ans : **SQP 2007**

The reciprocal of resistivity (ρ) of a material is called its electrical conductivity (σ), i.e.,

$$\sigma = \frac{1}{\rho}$$

SI unit of conductivity is $\text{mho} - \text{m}^{-1}$ (or siemen^{-1}).

117. What are the advantage of a Wheatstone bridge method of measuring resistance over other methods?

Ans : **Comp 2010**

1. It is a null method, hence the result is free from the effect of extra resistances (cell resistances) of the circuit.
2. Being null method, it is easier to detect a small change in deflection than to read a deflection directly.

118. A wire of resistivity ρ is stretched to double its length. What will be its new resistivity?

Ans : **SQP 2014**

Resistivity of wire is given by,

$$\rho = \frac{RA}{l} \quad ...(1)$$

Specific resistance or resistivity of the conductor depends upon the nature of the material and temperature of the conductor. So its remains same.

119. What is the advantage of using thick metallic strips to join wires in a potentiometer?

Ans : **Main 2019**

The metal strips have low resistance and need not be counted in the potentiometer length l of the null point. One measures only their lengths along the straight segments (of length 1 metre each). This is easily done with the help of centimetre rulings or meter ruler and leads, to accurate measurements.

120. Define mobility of a charge carrier. What is its relation with relaxation time?

Ans : **SQP 2011, 2009**

It is defined as how fast electron moves from one place to another.

It is also defined as drift velocity per unit electric field. The SI unit of mobility is $\text{m}^2/\text{V} - \text{sec}$ and it is denoted as μ.

$$\mu = \frac{|v_d|}{E} = \frac{eE\tau}{mE} = \frac{e\tau}{m}$$

$$\mu \propto \tau$$

121. Define current density. Write an expression which connects current density with drift speed.

Ans : **Main 2018**

The ratio of current flowing at any point in a conductor to the area of cross-section at that place is defined as current density.

$$J = \frac{I}{A}$$

The current density at any point of conductor in terms of drift velocity is, $J = nev_d$

where, $v_d =$ drift velocity.

122. Define drift velocity and relaxation time, with reference to the free electron theory of conductors.

Ans : **Main SQP 2018**

Drift velocity is defined as the average velocity with which the free electron get drifted towards the positive end of the conductor under the influence of an external electric field applied.

Relaxation time The average time that has been elapsed since each electron suffered its last collision with ion/atom of conductor is called relaxation time.

123. What is current density? Write the vector equation connecting current density J with electric field intensity E, for an ohmic conductor.

Ans : **Main 2025, 2010**

The ratio of current flowing at any point in a conductor to the area of cross-section at that place is defined as current density.

$$|\vec{J}| = \frac{I}{|\vec{A}|}$$

In vector form, current density $\vec{J} = \sigma\vec{E}$

where, $\sigma =$ conductivity.

$E =$ electric field across the conductor.

124. Define current density. Is it a scalar or vector quantity? Give its SI unit.

Ans : **SQP 2016**

It is the amount of charge flowing per second per unit area normal to the flow of charge. It is a vector quantity having the same direction as that of the motion of the positive charge.

For normal flow of charge,

$$j = \frac{q/t}{A} = \frac{I}{A}$$

In general, $I = jA\cos\theta = \vec{j} \cdot \vec{A}$

SI unit of current density $= \text{Am}^{-2}$.

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the influence of an electric field applied across the conductor. It is denoted by v_d. The drift velocity of an electron is of the order $10^{-4}\,\text{ms}^{-1}$.

Average drift velocity,

$$v_d = \frac{eE}{m}\tau$$

$v_d = \tau =$ average relaxation time

$E =$ electric field

$e =$ charge on electron

112. If the potential difference applied across a variable resistor is constant, draw a graph between the current in the resistor and the resistance.

Ans : **Main 2000**

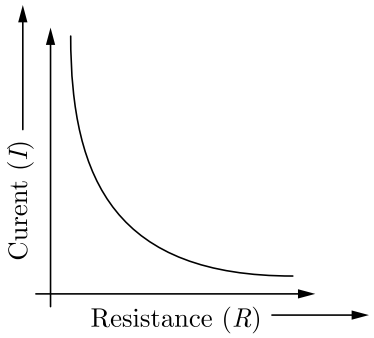
According to the Ohm's law, $V = IR$

Now, if $V =$ constant

So, $I \propto \frac{1}{R}$

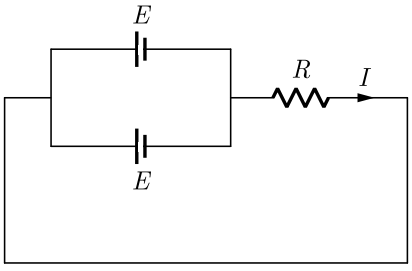
where, $I =$ current, $R =$ variable resistance

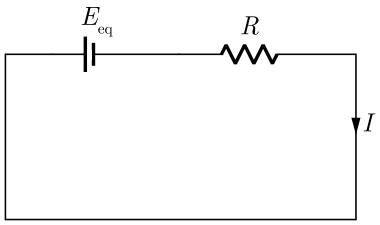
The variation is shown in the diagram.



113. Two identical cells, each of emf E, having negligible internal resistance, are connected in parallel with each other access an external resistance R. What is the current through this resistance?

Ans : **Comp 2021, 2017**





$$I = \frac{E_{eq.}}{R + r_{eq.}}$$

internal resistance, $r = 0$

$$I = \frac{E_{eq.}}{R}$$

114. A current I flows through a metallic wire of radius r and free electrons in it drift with a velocity v_d. Calculate the drift velocity of the free electrons through the wire of the same material, having double the radius, when same current flows through it.

Ans : **Main 2014**

$$J = nev_d$$

$$\frac{I}{A} = nev_d$$

$$v_d = \frac{I}{neA} \quad ...(1)$$

As radius is doubled

$$A' = 4A \left[\begin{matrix}\text{as } A = \pi r^2 \\ A' = \pi(2r)^2\end{matrix}\right]$$

As $$v'_d = \frac{1}{ne4A} \quad ...(2)$$

So, from Eqs. (1) and (2),

$$\frac{v'_d}{v_d} = \frac{A}{A'} = \frac{A}{4A}$$

$$v'_d = \frac{1}{4}v_d$$

TWO MARKS QUESTIONS

115. Define the term conductivity of a conductor. On what factors does it depends?

Ans : **SQP 2017**

Conductivity of a conductor is defined as the current flowing per unit area per unit electric field applied. It denotes as σ. So, conductivity $(\sigma) = \frac{J}{E}$. It depends upon number density, i.e., nature of material and also relaxation time, i.e., temperature.

NODIA

Ans : **Main 2005**

drift velocity

$$v_d = \frac{eV}{ml} \times \tau$$

where, V = potential difference

m = mass of the electron

l = length of the wire

τ = relaxation time

(i) If V is doubled, then drift velocity will also be double.

(ii) If l is doubled, then drift velocity will be half.

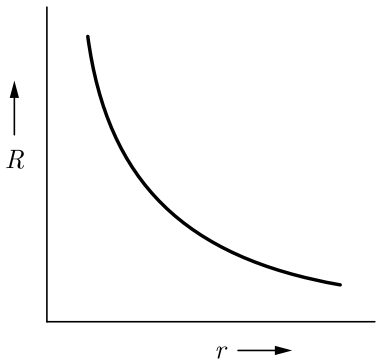
132. Plot a graph showing the variation of resistance of a conducting wire as a function of its radius, keeping the length of the wire and its temperature as constant.

Ans : **Main 2015**

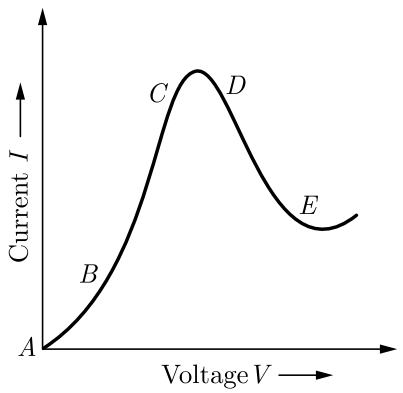
Resistance of a conductor of length l and radius r is given by

$$R = \rho\frac{l}{\pi r^2}$$

Hence, $$R \propto \frac{1}{r^2}$$



133. Graph showing the variation of current versus voltage to a material GaAs is shown in the figure. Identify the region of



(i) negative resistance.

(ii) where Ohm's law is obeyed ?

Ans : **SQP 2020, 2017**

(i) In region DE, material GaAs (Gailium Arsenide) others negative resistance, because slope $\frac{\Delta V}{\Delta I} < 0$.

(ii) The region BC, approximately passes through the origin, (or current also increases with the increase of voltage). Hence, it follows Ohm's law and in this region $\frac{\Delta V}{\Delta I} > 0$.

134. Name one material whose resistivity decreases with rise in temperature. Explain briefly on the basis of free electron theory why the resistivity decreases.

Ans : **Main 2000**

Resistivity in semiconductors like germanium or silicon decreases with rise in temperature i.e., their temperature coefficient of resistance is negative.

The reason is that, for such substance e.g., silicon, the value of n (the number of free electrons in unit volume) is very small compared to the metals; but with rise in temperature the number of free electrons i.e., the value of n goes on increasing in the conduction band. Therefore, the resistance $R = \left(\frac{ml}{\tau e^2 nA}\right)$ goes on decreasing. Although in these substances also the relaxation time τ decreases with rise in temperature but the increase in the value of n is large compared to the decrease in τ. Hence, the net effect of rise in temperature is that the resistance decreases.

135. Current I flowing through a metallic wire is related to drift speed v_d of free electrons as follows.

$$I = nAev_d$$

State what the symbol n stands for.

Ans : **Main 2004**

Electric current

$$I = \frac{q}{t} = \frac{nALe}{t} = \frac{nALe}{L/v_d}$$

drift velocity's electric current,

$$I = neAv_d$$

where, n = number density of free electrons,

e = electronic charge,

A = cross-sectional area,

v_d = drift velocity of an electron

and L = length of the conductor.

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145. Derive an expression for the resistivity of a conductor in terms of number density of free electrons and relaxation time.

Ans : **Main 2011**

The resistance R of a conductor of length l, area of cross-section A and resistivity ρ is given by,

$$R = \rho\frac{l}{A}$$

But, $$R = \frac{ml}{ne^2\tau A}$$

where, τ is the relaxation time. Comparing the above two equations, we get

$$\rho = \frac{m}{ne^2\tau}$$

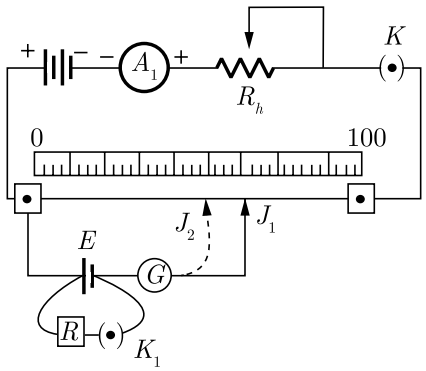
Obviously, ρ is independent of the dimensions of the conductor but depends on its two parameters:

(a) Number of free electrons per unit volume or electron density of the conductor.

(b) The relaxation time τ, the average time between two successive collisions of an electron.

146. Draw a labelled circuit diagram of a potentiometer to measure internal resistance of a cell. Write the working formula. (Derivation not required).

Ans : **Main 2016, 2015**



The working formula is $$r = \left(\frac{l_1}{l_2} - 1\right)R$$

Thus, knowing the values of l_1, l_2 and R, the internal resistance r of the cell can be determined.

147. Write down a simple relationship to show the variation of resistance with temperature. Define temperature coefficient of resistance. In what way the temperature coefficient of carbon is different from that of the common conductors?

Ans : **Main 2001**

The variation of resistance with temperature is given by the relation

$$R_t = R_0(1 + \alpha t) \qquad ...(1)$$

where, R_t and R_0 are the resistance of the conductor at t °C and 0°C respectively and a is the temperature coefficient of the resistance.

Using equation (1), we get

$$\alpha = \frac{R_t - R_0}{R_0 t}$$

Then temperature coefficient of resistances is defined as the change in resistance per unit original resistance for each degree rise in temperature.

The temperature coefficient of carbon. (a semiconductor) is negative whereas for metals, it is positive. Thus, the resistance of carbon falls when its temperature increases.

148. Using theory of drift velocity, express Ohm's law.

Ans : **Main 2018, 2015**

When a potential difference V is applied across a conductor of length l, the drift velocity in terms of V is given by

$$v_d = \frac{eE\tau}{m} = \frac{eV\tau}{ml} \qquad \left(E = \frac{V}{l}\right)$$

If the area of cross-section of the conductor is A and the number of electrons per unit volume or the electron density of the conductor is n, then the current through the conductor will be

$$I = enAv_d = enA \cdot \frac{eV\tau}{ml}$$

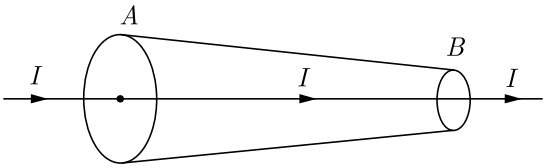
or, $$\frac{V}{I} = \frac{ml}{ne^2\tau A}$$

At a fixed temperature, the quantities m, l, n, e, τ and A, all have constant values for a given conductor. Therefore,

$$\frac{V}{I} = \text{a constant, } R$$

This proves Ohm's law for a conductor.

149. A metallic plug AB is carrying a current I (see figure below). State how the drift velocity of free electrons varies from end A to B.



Ans :

$$J = nev_d$$

$$\frac{I}{A} = nev_d \Rightarrow v_d \propto \frac{1}{A}$$

[n, e, I, and v_d are constants]

NODIA

140. With reference to free electron theory of conductors, define.

(a) Drift velocity.

(b) State any one use of a potentiometer.

Ans : **Main 2023, 2016**

(a) It is defined as the average velocity with which the free electrons in a conductor get drifted towards the positive end of the conductor under the influence of an electric field applied across the conductor. It is denoted by v_d. The drift velocity of an electron is of the order $10^{-4}\,\text{ms}^{-1}$.

(b) It is an electrical device which can be used for the following purposes.

(i) Measure the potential difference with greater accuracy.

(ii) Compare the emfs of two cells.

(iii) Measure the emf of a cell.

(iv) Used to determine the intimal resistance of a primary cell.

The potentiometer works on the principle that the potential difference across any two points of uniform current carrying conductor is directly proportional to the length between the two points of the wire of potentiometer i.e.,

$$V \propto l$$

where $k =$ constant of proportionality called the potential

$$k = \frac{V}{t}$$

So the potential gradient is defined as the potential drop per unit length of potentiometer wire.

THREE MARKS QUESTIONS

141. Why is the use of a potentiometer preferred over that of a voltmeter for measurement of emf of a cell?

Ans : **Main 2013**

Potentiometer is a null method device. No current is draw from the cell at null point, thus there is no potential drop due to the internal resistance of the cell. So it measures the potential difference in an open circuit. But voltmeter requires a small current for its operation. So voltmeter measures the potential difference in a closed circuit which is less than the actual emf of the cell.

142. What is meant by

(a) drift velocity

(b) relaxation time?

Ans : **Main 2009**

(a) **Drift velocity** It is defined as the average velocity with which the free electron get drifted towards the positive end of the conductor under the influence of an external electric field applied.

(b) **Relaxation time** The average time that has been elapsed since each electron suffered its last collision with ion/atom of conductor is called relaxation time.

NODIA

143. Define mobility of a charge carrier. Express it in terms of relaxation time. Give its SI and practical units.

Ans : **Main 2024, 2018**

The mobility of a charge carrier is the magnitude of the drift velocity acquired per limit electric field. It is given by

$$\mu = \frac{v_d}{E}$$

As drift velocity, $v_d = \frac{qE\tau}{m}$

Hence, $\mu = \frac{v_d}{E} = q\frac{\tau}{m}$

For an electron, $\mu_e = \frac{e\tau_e}{m_e}$

For a hole, $\mu_h = \frac{e\tau_h}{m_h}$

SI unit of mobility $= \text{m}^2\text{V}^{-1}\text{S}^{-1}$ or $\text{ms}^{-1}\text{N}^{-1}\text{C}$

Practical unit of mobility $= \text{cm}^2\text{V}^{-1}\text{s}^{-1}$

144. What is internal resistance of a cell? On what factors does it depend?

Ans : **Main 2016**

The resistance offered by the electrolyte of a cell to the flow of current between its electrodes is called **internal resistance** of the cell.

Factors on which internal resistance of a cell depends :

1. Nature of the electrolyte.
2. It is directly proportional to the concentration of the electrolyte.
3. It is directly proportional to the distance between the two electrodes.
4. It varies inversely as the common area of the electrodes immersed in the electrolyte.
5. It increases with the decrease in temperature of the electrolyte.

As the direction of current density $\vec{j}$ is same as that of electric field $\vec{E}$, we can write the above equation as,

$$\vec{E} = \rho\vec{j}$$

$$\vec{j} = \sigma\vec{E}$$

The above equation is the vector form of Ohm's law. It is equivalent to the scalar form,

$$V = RI$$

154. Define the term current density of a metallic conductor. Deduce the relation connecting current density (J) and the conductivity σ of the conductor, when an electric field E, is applied to it.

Ans : **SQP 2025**

Current density at a point in a conductor is defined as the amount of current flowing per unit area of the conductor around that point provided the area is held in a direction normal to the current,

$$J = \frac{I}{A}$$

Current density is a vector quantity. Its direction is the direction of motion of positive charge. The unit of current density is ampere/metre^2 or $[Am^{-2}]$.

Relation between J, σ and E

$$I = nAev_d = nA \cdot e\left(\frac{eE}{m}\tau\right)$$

$$= \frac{nAe^2\tau E}{m}$$

$$\frac{I}{A} = \frac{ne^2\tau E}{m}$$

$$J = \frac{I}{\rho}E \qquad \left[\text{since } J = \frac{I}{A} \text{ and } \rho = \frac{m}{ne^2\tau}\right]$$

Hence, $I = \sigma E \qquad \left[\text{since } \sigma = \frac{1}{\rho}\right]$

155. Derive Ohm's law on the basis of the theory of electron drift.

Ans : **Main 2015**

Deduction of Ohm's law : If m is the mass of an electron and τ is the relaxation time, then drift velocity,

$$v_d = \frac{eE\tau}{m} = \frac{eV\tau}{ml} \qquad \left[\text{since } E = \frac{V}{l}\right]$$

Hence, Current,

$$I = enAv_d = enA \cdot \frac{eV\tau}{ml}$$

$$\frac{V}{I} = \frac{ml}{ne^2\tau A}$$

At a fixed temperature, the quantities m, l, n, e, τ and A, all have constant value for a given conductor.

Therefore, $\frac{V}{I} = \text{a constant } R$

This proves Ohm's law for a conductor and here

$$R = \frac{ml}{ne^2\tau A}$$

is the resistance of the conductor.

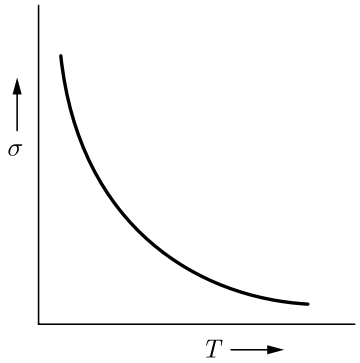
156. Explain the variation of conductivity with temperature for (i) a metallic conductor and (ii) ionic conductors.

Ans : **Main 2019**

(i) Conductivity of a metallic conductor

$$\sigma = \frac{1}{\rho} = \frac{ne^2\tau}{m}$$

with raise of temperature, the collision of electrons with fixed lattice ions/atoms increases so that relaxation time (τ) decreases. Consequently, the conductivity of metals decreases with rise of temperature.



(ii) Conductivity of ionic conductor increases with increase of temperature because with increase of temperature, the ionic bonds break releasing positive and negative ions which are charge carriers in ionic conductors.

157. Derive an expression for drift velocity of free electrons.

Ans : **Main 2016**

When a potential difference is applied across a conductor, an electric field is produced and free electrons are acted upon an electric force (F_e). Due to this, electrons accelerate and keep colliding with each other and acquire a constant (average) velocity v_d called drift velocity.

Electric force on electron $F_e = -eE$

If m is the mass of electron, then its acceleration

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where, n = no. of free electrons

e = electron charge

v_d = drift speed

A = area of cross-section

So, drift velocity (v_d) at A is smaller than at B.

Because area of cross-section A is larger than B.

150. Obtain the formula for the power loss (i.e. power dissipated) in a conductor of resistance R carrying a current.

Ans : **Main 2017**

It is defined as the rate of electrical energy supplied per unit time to maintain flow of electric current through a conductor.

Mathematically, $P = VI = I^2R = \frac{V^2}{R}$

Where, 1 watt = 1volt × 1 ampere

= 1 ampere-volt.

Power of an electric circuit is said to be one watt, if one ampere current flows in it against a potential difference of one volt. The bigger units of electrical power are kilowatt (kW) and megawatt (MW).

Where 1 kW = 1000 W

and MW = 10^6W.

Commercial unit of electrical power is horse power (HP).

Where, 1 HP = 746 W.

151. What are the factors on which resistance of a conductor depends? Give the corresponding relation.

Ans : **Main 2020**

At a constant temperature, the resistance of a conductor depends on the following factors:

1. **Length :** The resistance R of a conductor is directly proportional to its length i.e., $R \propto l$.
2. **Area of cross-section :** The resistance R of a uniform conductor is inversely proportional to its area of cross-section A, i.e., $R \propto \frac{1}{A}$.
3. **Nature of the material :** The resistance of a conductor also depends on the nature of its material.

Combining the above factors, we get,

$$R \propto \frac{l}{A}$$

$$R = \rho\frac{l}{A}$$

Where ρ is the constant of proportionality called resistivity or specific resistance of the material of the conductor. It depends on the nature of the material of the conductor and on the physical conditions like temperature and pressure.

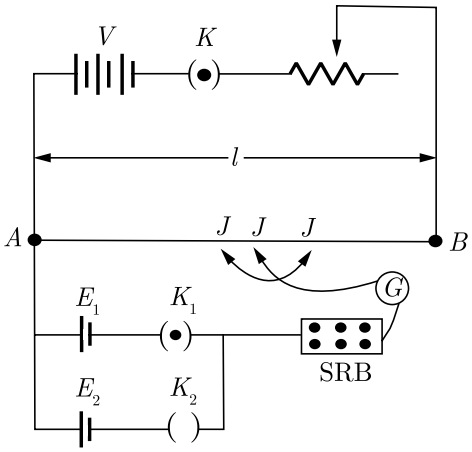
152. Draw a labelled circuit diagram of a potentiometer to compare emfs of two cells. Write the working formula (Derivation not required).

Ans : **Main 2014, 2001**

Potentiometer works on the principle of null deflection. The emf measured is proportional to length of the wire.

The circuit diagram for comparing the emfs is shown. The emfs of two primary cells can be compared using potentiometer as

$$\frac{E_1}{E_2} = \frac{l_1}{l_2}$$



where l_1 and l_2 are the balancing lengths corresponding to the cells of emfs E_1 and E_2 respectively.

153. Express Ohm's law in vector form.

Ans : **Main 2019**

If E is the magnitude of electric field in a conductor of length l, then the potential difference across its end is,

$$V = El$$

Also from Ohm's law, we can write

$$V = IR = \frac{I\rho l}{A}$$

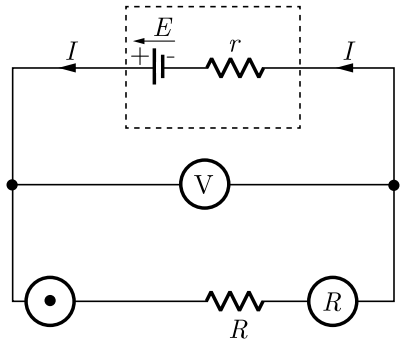
Hence, $$El = \frac{I}{A}\rho l$$

$$E = j\rho$$

Ans : **Main 2007**

Work done by a battery of emf E, when charge dq passes through the battery is (dqE). Work done in carrying a unit positive charge in a circuit is defined as emf of a cell.

Suppose, when a steady current I is established in a circuit containing a cell of emf E, internal resistance r and an external resistance R, a charge dq flows in the circuit in time dt. By the definition of emf and according to Joule's law, the work done by the cell is given by



$$dW = Edq = EI\,dt \qquad [dq = I\,dt]$$

If $V = IR$ be the potential difference across R, then the external work done by the cell is given by

$$dW_{\text{ext}} = V\,dq = VI\,dt$$
$$= I^2R\,dt \qquad \text{[by Joule's law]}$$

If $V = Ir$ be the potential drop across the internal resistance r, the internal work done by the cell is given by

$$dW_{\text{int}} = VI\,dt = I^2r\,dt \qquad \text{[by Joule's law]}$$

By the law of conservation of energy,

$$dW = dW_{\text{ext}} + dW_{\text{int}}$$
$$EI\,dt = I^2R\,dt + I^2r\,dt$$
$$E = I(R + r)$$

166. Define current density and relaxation time. Derive an expression for resistivity of a conductor in terms of number density of charge carriers in the conductor and relaxation time.

Ans : **Main 2023, 2018**

Current density is the amount of current travelling per unit cross-section area is known as current density and expressed in ampere per square meter.

Relaxation time is the time gap between two successive electron collisions in a conductor. The relationship between the relaxation time (t) and drift velocity $(v_d)$is given below

$$v_d = -e\left(\frac{E_t}{m}\right)$$

Derivation : Using ohm's law, we have

$$V = IR$$
$$\frac{V}{I} = R$$

Drift velocity is given by,

$$v_d = \frac{eE}{m}t$$

But, electric field, $E = \frac{V}{l}$

$$v_d = \frac{eV}{ml}t$$

Also, we have $I = neAv_d$

$$I = Ane\left(\frac{eV}{ml}t\right)$$
$$= \left(\frac{Ane^2t}{ml}\right)V$$

i.e. $\frac{V}{I} = \frac{ml}{Ane^2t} = R$

On comparing this equation with

$$R = \rho\frac{1}{A}$$

We can deduce an expression for resistivity ρ which is given by

$$\rho = \frac{m_e}{\eta e^2 t}$$

Where, η is the number density of charge carriers and t is the relaxation time.

167. Define the terms electric energy and electric power. Give their units.

Ans : **SQP 2010**

Electric Power : It is the rate at which an electric appliance converts energy into other forms of energy. Or, it is the rate at which work is done by a source of emf in maintaining an electric current through a circuit.

Electric power, $P = \frac{W}{t} = VI = I^2R = \frac{V^2}{R}$

SI unit of power is watt :

The power of an appliance is one watt if one ampere of current flows through it on applying a potential difference of 1 volt across it.

$$1 \text{ watt} = \frac{1 \text{ joule}}{1 \text{ second}}$$
$$= \frac{1 \text{ joule}}{1 \text{ coulomb}} \times \frac{1 \text{ coulomb}}{1 \text{ second}}$$
$$= 1\text{volt} \times 1 \text{ ampere}$$
$$1\,\text{W} = 1\text{Js}^{-1} = 1\,\text{VA}$$
$$1 \text{ kilowatt (kW)} = 1000\,\text{W}$$

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$$a = \frac{F_e}{m} = \frac{-e\vec{E}}{m}$$

Now, $v = u + at$

Here, $u = 0$

$t = \tau$ (relaxation time),

$\vec{v} = \vec{v_d}$

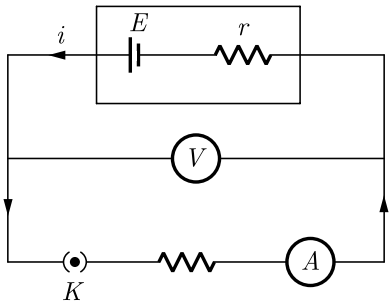
$$\vec{v_d} = 0 - \frac{e\vec{E}}{m}\tau$$

$$\vec{v_d} = -\frac{e\tau}{m}\vec{E}$$

158. A cell of emf 'E' and internal resistance 'r' is connected across a variable resistor 'R' Plot a graph showing the variation of terminal potential 'V' with resistance R. Predict from the graph the condition under which 'V' becomes equal to 'E'

Ans : Comp 2009

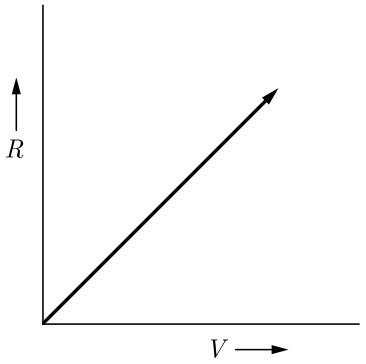
From figure (a)



$$V = E - ir$$

and $V = iR$

Required graph is as shown in figure (b)



When circuit is open (i.e., $i = 0$),

then $E = V$

159. Three resistances R_1, R_2 and R_3 are connected in series. Find their equivalent resistance.

Ans : SQP 2013, 2011

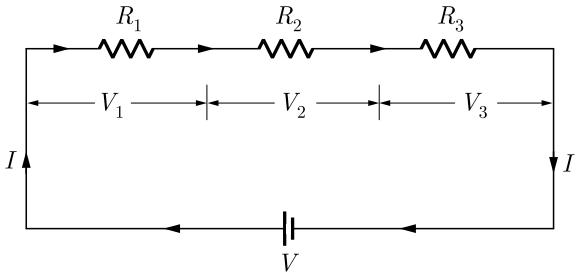


Figure shows three resistances R_1, R_2 and R_3 connected in series. When a potential difference V is applied across the combination, the same current I flows through each resistance.

By Ohm's law, the potential drops across the three resistances are,

$$V_1 = IR_1$$

$$V_2 = IR_2$$

$$V_3 = IR_3$$

If R_s is the equivalent resistance of the series combination then we must have,

$$V = IR_s$$

But, $V = V_1 + V_2 + V_3$

$$IR_s = IR_1 + IR_2 + IR_3$$

$$R_s = R_1 + R_2 + R_3$$

Thus when a number of resistances are connected in series, their equivalent resistance is equal to the sum of the individual resistances.

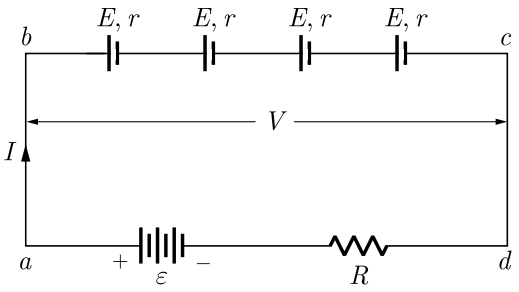
160. n-identical cells, each of emf ε, internal resistance r connected in series are charged by a DC source of emf ε', using a resistance R.

(i) Draw the circuit arrangement.

(ii) Deduce expressions for (a) the charging current and (b) the potential difference across the combination of cells.

Ans : SQP 2008

(i) The circuit arrangement is shown in figure :



DC source

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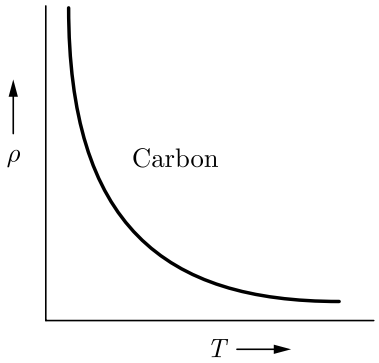
136. Sketch a graph showing the variation of resistivity of carbon with temperature.

Ans : **Comp 2008**

The resistivity of a typical semiconductor (carbon) decreases with increase a temperature. The graph is shown in figure.



In semiconductor the number density of free electrons n increases with increase in temperature T and consequently the relaxation period decreases. But the effect of increase in h has higher impact than decrease of τ. So, resistivity decreases with increase in temperature.

137. State Kirchhoff's rules of current distribution in an electrical network.

Ans : **SQP 2013, 2017**

Junction rule in an electric circuit, the algebraic sum of currents in any junction is zero.

At any junction, the sum of the currents entering the junction is equal to the sum of currents leaving the junction.

$$\Sigma I = 0$$

Justification : This rule is based on the law of conservation of charge.

Loop rule : The algebraic sum of charges in potential around any closed loop involving resistors and cells in the loop must be zero.

$$\Sigma \triangle V = 0$$

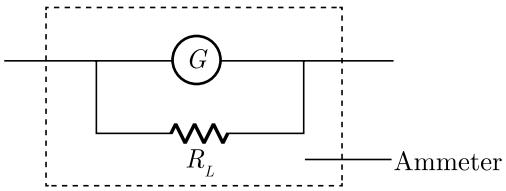
Justification : This rule is based on the law of conservation of energy.

138. You are provided with one low resistance R_L and one high resistance R_H and two galvanometers. One galvanometer is to be converted to an ammeter and the other to a voltmeter. Show how you will do this with the help of simple, labelled diagrams.

Ans : **Main 2013**

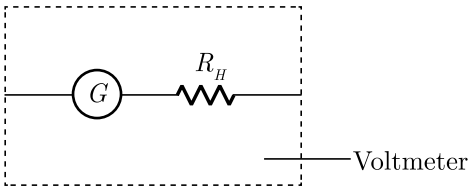
For conversion of galvanometer into ammeter a low resistance is connected in parallel. Similarly to convert to voltmeter a high resistance is connected in series.

Conversion of galvanometer into ammeter



R_L = low resistance or shunt resistance

Conversion of galvanometer into voltmeter



R_H = high resistance

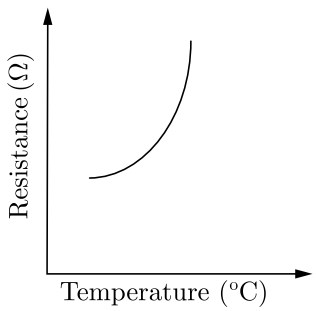
139. Draw labelled graphs to show how electrical resistance varies with temperature for

(i) a metallic wire

(ii) a piece of carbon

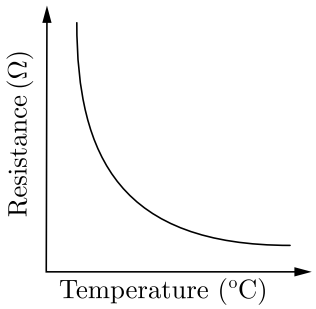
Ans : **Main 2015**

(i) The resistance of metal increases exponentially with temperature as shown in the graph.



Graph for metoallic wire

(ii) The resistance of carbon decreases exponentially with temperature as shown in the graph.



Graph for a piece of carbon

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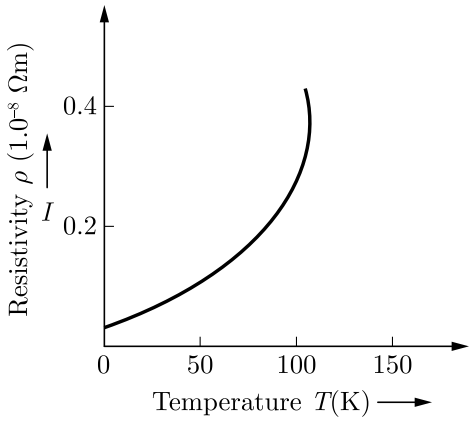
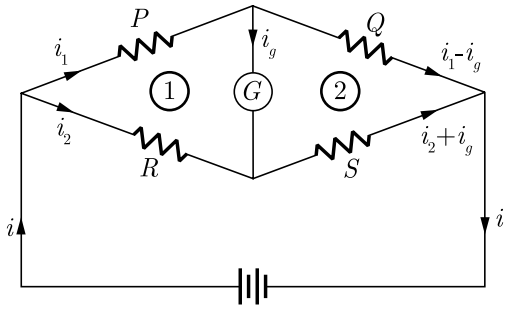


Resistivity ρ_1 of metallic conductor as a function of temperature.

163. With the help of a neatly drawn and labelled diagram, obtain balancing condition of a Wheatstone bridge.

Ans : **Main 2015, 2012, 2002**

In case of balanced Wheatstone bridge the current through the galvanometer is zero. The labelled diagram of Wheatstone bridge is given



P, Q, R and S are the arm resistance of Wheatstone bridge.

Proof By Kirchhoff's law

In loop 1,

$$-i_1P - i_gG + i_2R = 0 \quad ...(1)$$

In loop 2,

$$-(i_1 - i_g)Q + (i_2 + i_g)S + i_gG = 0 \quad ...(2)$$

If there is no current in galvanometer i.e., $i_g = 0$, then Wheatstone bridge will be balance, then Eqs. (1) and (2) gives

$$i_1P - i_2R = 0$$

$$i_1P = i_2R \quad ...(3)$$

$$i_1Q - i_2S = 0$$

$$i_1Q = i_2S \quad ...(4)$$

On dividing Eq. (3) by Eq. (4), we get

$$\frac{P}{Q} = \frac{R}{S}$$

$$PS = QR$$

i.e., product of resistances of opposite arms are equal.

164. Give some important points of differences between electromotive force and potential difference.

Ans : **Comp 2021**

Differences between electromotive force and potential difference are as follows:

	Electromotive Force	**Potential Difference**
1.	It is the work done by a source in taking a unit charge once round the complete circuit.	It is the amount of work done in taking a unit charge form one point of a circuit to another.
2.	It is equal to the maximum potential difference between the two terminals of a source when it is in an open circuit.	Potential difference may exist between any two points of a closed circuit.
3.	It exists even when the circuit is not closed.	It exists only when the circuit is closed.
4.	It is a cause. When emf is applied in a circuit, potential difference is caused.	It is an effect.
5.	It is equal to the sum of potential differences across all the components of a circuit including the potential difference required to send current through the cell itself.	Every circuit component has its own potential difference across its ends.
6.	It is larger than the potential difference across any circuit element.	It is always less than the emf.

165. Define the emf of a cell in terms of the work done in moving a charge through the cell.

Using Joule's law obtain the equation, emf $= I(R + r)$. (The symbols have their usual meaning).

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(ii) Applying Kirchhoff's second law to the circuit $abcda$

$$-ne - I(nr) - IR + \varepsilon' = 0$$

$$I = \frac{\varepsilon' - n\varepsilon}{R + nr}$$

(a) Charging current,

$$I = \frac{\varepsilon' - n\varepsilon}{R + nr} \quad ...(1)$$

(b) Potential difference across the combination V is given by

$$-V - IR + \varepsilon' = 0$$

$$V = \varepsilon' - IR$$

$$V = \varepsilon' - \frac{(\varepsilon' - n\varepsilon)}{R + nr}$$

$$V = \frac{\varepsilon'(R + nr) - \varepsilon' + n\varepsilon}{R + nr}$$

$$V = \frac{\varepsilon'(R + nr - 1) + n\varepsilon}{R + nr}$$

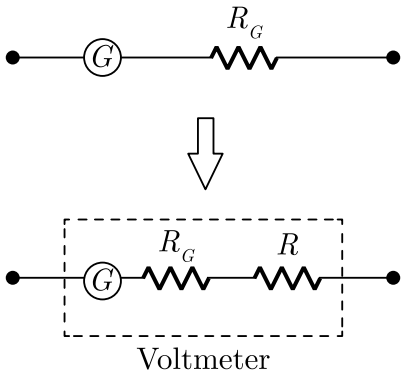
161. How is a galvanometer converted into a voltmeter and an ammeter? Draw the relevant diagrams and find the resistance of the arrangement in each case. Take resistance of galvanometer as G.

Ans : **SQP 2016**

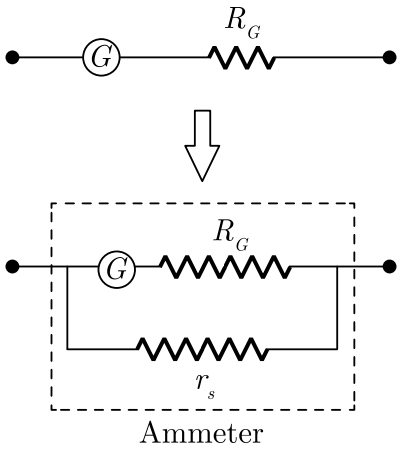
A galvanometer is converted into a voltmeter by connecting a high resistance R in series with it.

A galvanometer is converted into an ammeter by connecting a small resistance (called shunt) in parallel with it.

Resistance of voltmeter, $R_V = G + R$



Resistance of Ammeter, $R_A = \frac{Gr_s}{G + r_s}$



162. Define resistivity of a conductor. Plot a graph showing the variation of resistivity with temperature for a metallic conductor. How does one explain such a behaviour, using the mathematical expression of the resistivity of a material.

Ans : **SQP 2006**

, $$R = \rho\frac{l}{A}$$

If $$l = 1,$$

$$A = 1$$

$$\rho = R$$

Thus, resistivity of a material is numerically equal to the resistance of the conductor having unit length and unit cross-sectional area.

The resistivity of a material is found to the dependent on the temperature. Different materials do not exhibit the same dependence on temperature. Over a limited range of temperatures that is not too large, the resistivity of a metallic conductor is approximately given by,

$$\rho_T = \rho_O[1 + \alpha(T - T_O)] \quad ...(1)$$

Where ρ_T is the resistivity at a temperature T and ρ_O is the same at a reference temperature $T_O \cdot \alpha$ is called the temperature co-efficient of resistivity.

Relation (1) implies that a graph of ρ_T plotted against T would be a straight line. At temperatures much lower than 0°C, the graph, however, deviates considerably from a straight line.

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Electric Energy : It is the total work done in maintaining an electric current in an electric circuit for a given time.

$$\text{Electric energy} = \text{Electric power} \times \text{time}$$
$$W = Pt$$
$$= VI\,t \text{ joule} = I^2Rt \text{ joule}$$

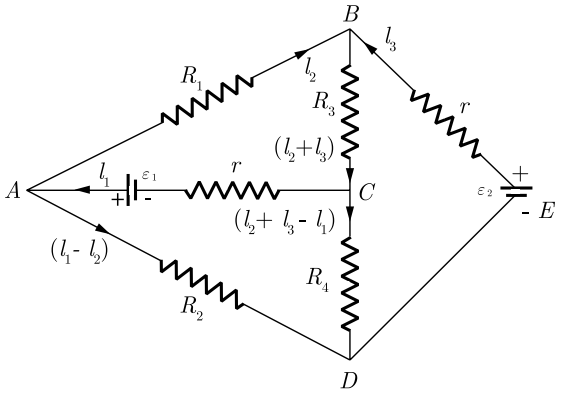
Units of Electric Energy : The commercial unit of electric energy is kilowatt-hour (kWh) or Board of Trade (B.O.T.) unit. It is the electric energy consumed by an appliance of power 1000 watt in one hour.

$$1\,\text{kWh} = 1000\,\text{Wh}$$
$$= 1000\,\text{W} \times 3600\,\text{s}$$
$$= 6 \times 10^6\,\text{J}$$

Another unit of electric energy is watt hour.

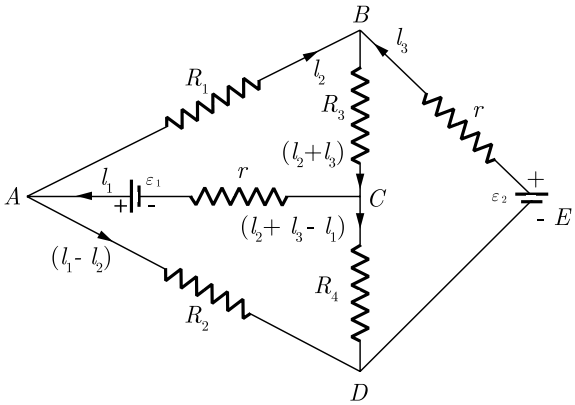
$$1 \text{ watt hour} = 1\,\text{W} \times 1\,\text{H}$$
$$= 3.6 \times 10^3\,\text{J}$$

168. Use Kirchhoff's rules to write the three equations that may be used to obtain the values of three unknown currents in the branches (shown) of the given circuit.



Ans : **Main 2012**

The distribution of current is shown in given figure.



Applying Kirchhoff's II law in loop $ABCA$

$$-I_2R_1-(I_2+I_3)R_3-I_1r+\varepsilon_1 = 0$$
$$I_1r+I_2(R_1+R_3)+I_3R_3 = \varepsilon_1 \quad ...(1)$$

Applying Kirchhoff's II law to loop $ACDA$,

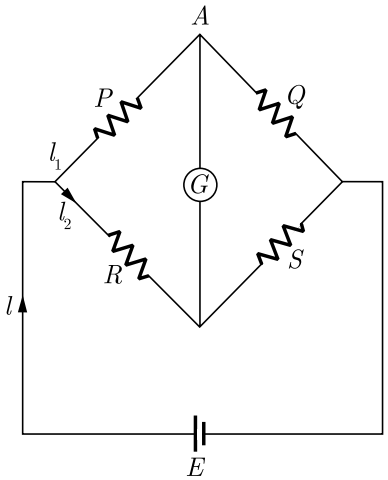
$$-\varepsilon_1+I_1r-(I_2+I_3-I_1)R_4+(I_3-I_2)R_2 = 0$$
$$I_1(r+R_2)-(R_2+R_4)I_2-I_3R_4 = 0 \quad ...(2)$$

In loop $BEDB$,

$$I_3r-\varepsilon_2+(I_2+I_3-I_1)R_4+(I_2+I_3)R_3 = 0$$
$$-I_1R_4+I_2(R_3+R_4)+I_3(r+R_3+R_4) = \varepsilon_2 \quad ...(3)$$

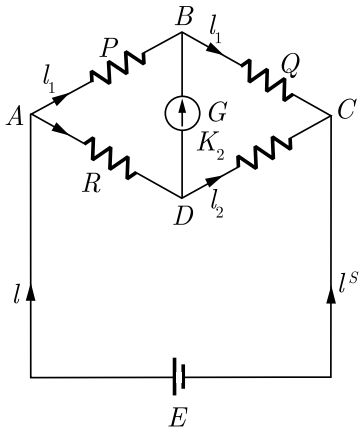
Equations (1), (2) and (3) are required equations.

169. Obtain the balancing condition for the Wheatstone bridge arrangement as shown in the figure given below.



Ans : **Main 2025**

In figure, four resistances P, Q, R and S are connected in the four arms of a parallelogram $ABCD$. Between B and D there is a sensitive galvanometer and a cell is connected between A and C. A current I is allowed to flow from the cell. At the point A, the current I is divided into two parts.



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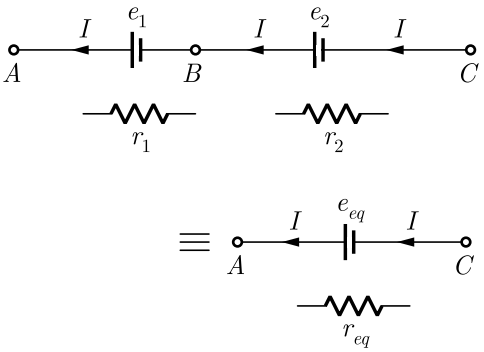
move and so the conductivity increases or resistivity decreases.

4. **Electrolyte :** As the temperature increases, the inter-ionic attractions (solute-solute, solvent-solute and solvent-solvent type) decrease and also the viscous forces decrease, the ions move more freely. Hence conductivity increases or the resistivity decreases as the temperature of an electrolytic solution increases.

178. Two cells of different emfs and internal resistances are connected in series. Find expressions for the equivalent emf and equivalent internal resistance of the combination.

Ans : **Main 2025**

As shown in figure, suppose two cells of emfs e_1 and e_2 and internal resistances r_1 and r_2 are connected in series between points A and C. Let I be the current flowing through the series combination.



A Series Combination of two Cells is Equivalent to a Single Cell of emf e_{eq} and internal resistance r_{eq}

Let V_A, V_B and V_C be the potential at points A , B and C respectively. The potential differences across the terminals of the two cells will be,

$$V_{AB} = V_A - V_B = e_1 - Ir_1$$

and $$V_{BC} = V_B - V_C = e_2 - Ir_2$$

Thus the potential difference between the terminals A and C of the series combination is,

$$V_{AC} = V_A - V_C$$
$$= (V_A - V_B) + (V_B - V_C)$$
$$= (e_1 - Ir_1) + (e_2 - Ir_2)$$
$$V_{AC} = (e_1 + e_2) - I(r_1 + r_2)$$

If we wish to replace the series combination by a single cell of emf e_{eq} and internal resistance r_{eq} then,

$$V_{AC} = e_{eq} - Ir_{eq}$$

Comparing the last two equations, we get

$$e_{eq} = e_1 + e_2$$

and $$r_{eq} = r_1 + r_2$$

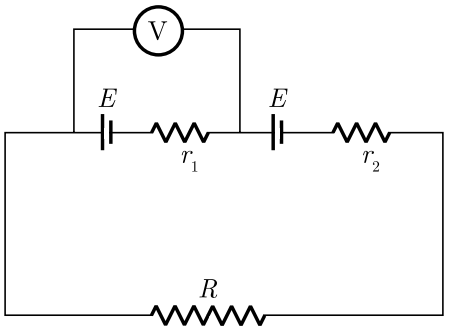
For a series combination of n cells,

$$e_{eq} = e_1 + e_2 + e_3 + ... + e_n$$

$$r_{eq} = r_1 + r_2 + r_3 + ... + r_n$$

179. Two cells of same emf E, but different internal resistances r_1 and r_2 are connected to an external resistance R as shown in the figure given below.

The voltmeter V reads zero. Obtain an expression for R in terms of r_1 and r_2. Calculate the voltage across the cell of internal resistance r_2. (Assume that the voltmeter V is of infinite resistance).



Ans : **Main 2005**

Find effective emf of the series combination of the cell. Then, current through the circuit can be

Calculated using $i = \frac{E_{\text{net}}}{r_{\text{net}}}$

As the two cells are in series, the effective emf is $2E$ and the total resistance is $r_1 + r_2 + R$.

Therefore, the current in the circuit is

$$i = \frac{2E}{r_1 + r_2 + R} \quad ...(1)$$

The voltage across the cell of internal resistance r_1 is

$$V = E - ir_1 = 0$$

[voltmeter V reads zero]

$$i = \frac{E}{r_1}$$

From Eqs. (1) and (2), we get

$$\frac{E}{r_1} = \frac{2E}{r_1 + r_2 + R}$$

$$R = r_1 - r_2$$

This is required relation.

The voltage across the cell of internal resistance r_2 is

$$V' = E - ir_2$$

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Figure shows three resistances R_1, R_2 and R_3 connected in parallel between points A and B. Let V be the potential difference applied across the combination.

Let I_1, I_2 and I_3 be the currents through the resistances R_1 , R_2 and R_3 respectively. Then the current in the main circuit must be,

$$I = I_1 + I_2 + I_3$$

Since all the resistances have been connected between the same two points A and B, therefore, potential drop V is same across each of them. By Ohm's law, the currents through the individual resistances will be,

$$I_1 = \frac{V}{R_1}$$

$$I_2 = \frac{V}{R_2}$$

$$I_3 = \frac{V}{R_3}$$

If R_p is the equivalent resistance of the parallel combination, then we must have,

$$I = \frac{V}{R_p}$$

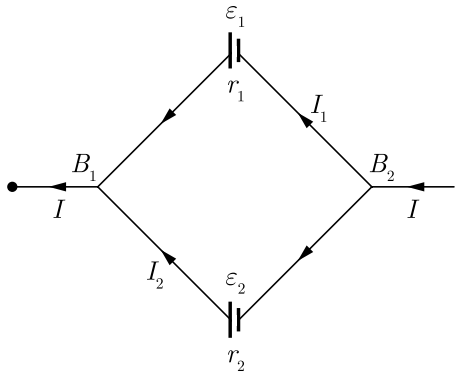
But, $$I = I_1 + I_2 + I_3$$

$$\frac{V}{R_p} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Thus when a number of resistances are connected in parallel, the reciprocal of the equivalent resistance of the parallel combination is equal to the sum of the reciprocals of the individual resistances.

172. Two cells of emf ε_1 and ε_2 having internal resistances r_1 and r_2 respectively are connected in parallel as shown. Deduce the expressions for the equivalent emf and equivalent internal resistance of a cell which can replace the combination between the point B_1 and B_2.



Ans : **Main 2009, 2012**

Consider a parallel combination of the cells I_1 and I_2 are the currents leaving the positive electrodes of the cells. At point B_1, I_1 and I_2 flow in whereas current I flows out. Therefore, we have

$$I = I_1 + I_2 \quad ...(1)$$

Let $V(B_1)$ and $V(B_2)$ be the potentials at B_1 and B_2 respectively.

Then, considering the first cell, the potential difference across its terminals is $V(B_1) - V(B_2)$. Hence, from equation $V = E - Ir$ we have

$$V = V(B_1) - V(B_2)$$

$$= E_1 - I_1 r_1 \quad ...(2)$$

Points B_1 and B_2 are connected exactly similarly to the second cell. Hence, considering the second cell, we also have

$$V = V(B_1) - V(B_2)$$

$$= E_2 - I_2 r_2 \quad ...(3)$$

Combining equations (1), (2) and (3), we have

$$I = \frac{E_1 - V}{r_1} + \frac{E_2 - V}{r_2}$$

$$= \left(\frac{E_1}{r_1} + \frac{E_2}{r_2}\right) - V\left(\frac{1}{r_1} + \frac{1}{r_2}\right) \quad ...(4)$$

Solving for (5), we have

$$V = \frac{E_1 r_2 - E_2 r_1}{r_1 + r_2} - I\frac{r_1 r_2}{r_1 + r_2} \quad ...(5)$$

If we want to replace the combination by a single cell, between B_1 and B_2, of emf E_{eq} and internal resistance r_{eq}, we would have

$$V = E_{eq} - Ir_{eq} \quad ...(6)$$

from eqs, (5) and (6) we have

$$E_{eq} - Ir_{eq} = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2} - I\frac{r_1 r_2}{r_1 + r_2}$$

Hence, we have $$E_{eq} = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}$$

and $$r_{eq} = \frac{r_1 r_2}{r_1 + r_2} \quad ...(7)$$

173. Define the term 'resistivity' and write its S.I. unit. Derive the expression for the resistivity of a conductor in terms of number density of free electrons and relaxation time.

Ans : **Comp 2012**

The resistivity of the material of a conductor is defined as the resistance of the unit length and unit area of cross section of the conductor. Its S.I. unit is $\Omega \cdot m$.

Consider a conductor of length l and of uniform cross sectional area A. Let there be n free electrons per unit volume of the conductor. Let

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Dividing Eq. (1) and by Eq. (2), we have

$$\frac{i_1 P}{i_1 Q} = \frac{i_2 R}{i_2 S}$$

or

$$\frac{P}{Q} = \frac{R}{S}$$

It is clear from this formula that if the ratio of the resistance P and Q and resistance R are known, then the unknown resistance S can be calculated. This is why, the arms AB and BC are called ratio arms, arm AD known arm and arm CD unknown arm.

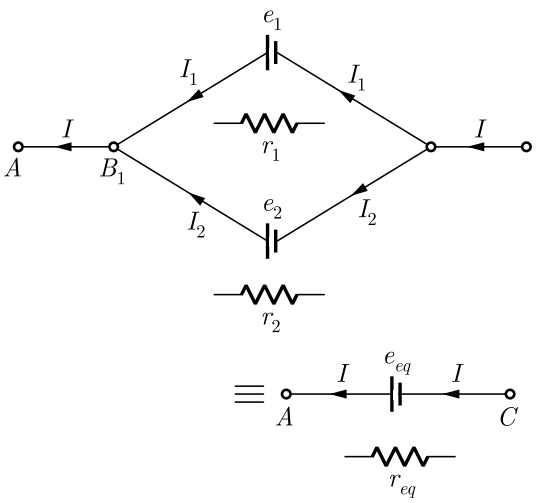
186. Two cells of emfs e_1 and e_2, and internal resistances r_1 and r_2 are connected in parallel between the points A and B. Deduce the expressions for

1. the equivalent emf of the combination.
2. the equivalent resistance of the combination.
3. the potential difference between the points A and B.

Ans : SQP 2019, 2013

As shown in figure, suppose two cells of emfs e_1 and e_2 and internal resistances r_1 and r_2 are connected in parallel between two points. Suppose the currents I_1 and I_2 from the positive terminals of the two cells flow towards the junction B_1 and current I flows out. Since as much charge flows in as flows out, we have

$$I = I_1 + I_2$$



A parallel Combination of two Cells is Equivalent to a Single Cell of emf e_{eq} and Internal Resistance r_{eq}

As the two cells are connected in parallel between the same two points B_1 and B_2, the potential difference V across both cells must be same.

The potential difference between the terminals of first cell is,

$$V = V_{B_1} - V_{B_2}$$
$$= e_1 - I_1 r_1$$

Hence,

$$I_1 = \frac{e_1 - V}{r_1}$$

The potential difference between the terminals of e_2 is,

$$V = V_{B_1} - V_{B_2} = e_2 - I_2 r_2$$

Hence,

$$I_2 = \frac{e_2 - V}{r_2}$$

Hence,

$$I = I_1 + I_2$$
$$= \frac{e_1 - V}{r_1} + \frac{e_2 - V}{r_2}$$
$$= \left(\frac{e_1}{r_1} + \frac{e_2}{r_2}\right) - V\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$
$$V\left(\frac{r_1 + r_2}{r_1 r_2}\right) = \frac{e_1 r_2 + e_2 r_1}{r_1 r_2} - I$$
$$V = \frac{e_1 r_2 + e_2 r_1}{r_1 + r_2} - I\frac{r_1 r_2}{r_1 + r_2}$$

If we wish to replace the parallel combination by a single cell of emf e_{eq} and internal resistance r_{eq} , then

$$V = e_{eq} - I r_{eq}$$

Comparing the last two equations, we get

$$e_{eq} = \frac{e_1 r_2 + e_2 r_1}{r_1 + r_2}$$

and

$$r_{eq} = \frac{r_1 r_2}{r_1 + r_2}$$

We can express the above results in a simpler way as follows:

$$\frac{e_{eq}}{r_{eq}} = \frac{e_1}{r_1} + \frac{e_2}{r_2}$$

and

$$\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2}$$

For a parallel combination of n cells, we can write,

$$\frac{e_{eq}}{r_{eq}} = \frac{e_1}{r_1} + \frac{e_2}{r_2} + ... + \frac{e_n}{r_n}$$

and

$$\frac{1}{r_{eq}} = \frac{1}{r_{eq}} + \frac{1}{r_1} + \frac{1}{r_2} + ... + \frac{1}{r_n}$$

187. State and explain Kirchhoff's law for electric circuits. What are the conservation laws implied in each law? State the sign convention for current and emf. Use the figure given along side for your explanation.

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Thus, there is no net flow of charge in any direction.

In the presence of an external field $\vec{E}$, each electron experiences a force $-e\vec{E}$ in the opposite direction of $\vec{E}$ (since an electron has negative charge) and undergoes an acceleration $\vec{a}$ given by

$$\vec{a} = \frac{\text{Force}}{\text{Mass}} = -\frac{e\vec{E}}{m}$$

where m is the mass of an electron. As the electrons accelerate, they frequently collide with the positive metal ions or other electrons of the metal. Between two successive collisions, an electron gains a velocity component (in addition to its random velocity) in a direction opposite to $\vec{E}$. However, the gain in velocity lasts for a short time and is lost in the next collision.

The average time that elapses between two successive collisions of an electron is called relaxation time. It is given by

$$\tau = \frac{t_1 + t_2 + ... + t_N}{N}$$

During the relaxation time τ, an electron gains an average velocity given by

$$\vec{v_d} = 0 + \vec{a}\,\tau \qquad [\text{since } v = u + at]$$

$$\vec{v_d} = -\frac{e\vec{E}\,\tau}{m}$$

The parameter $\vec{v_d}$ is called drift velocity of electrons. It may be defined as the average velocity gained by the free electrons of a conductor in the opposite direction of the externally applied electric field.

176. Define temperature coefficient of resistivity (α) . Distinguish between metals, semiconductor and alloys on the basis of their α values.

Ans : **Main 2021, 2014**

The temperature coefficient of resistivity may be defined as the increase in resistivity per unit resistivity per degree rise in temperature. It is given by

$$\alpha = \frac{\rho - \rho_0}{\rho_0(T - T_0)} = \frac{1}{\rho_0} \cdot \frac{d\rho}{dT}$$

Thus the resistivity ρ at any temperature T will be,

$$\rho = \rho_0[1 + \alpha(T - T_0)] \qquad ...(1)$$

Where ρ_0 is the resistivity at a lower reference temperature T_0 (usually 20° C).

As, $R = \rho\frac{l}{A}$

i.e., $R \propto \rho$

Hence, equation (1) can be written in terms of resistance as

$$R_t = R_0(1 + \alpha t)$$

Where, R_t = the resistance at t° C

R_0 = the resistance at 0° C

and t = the rise in temperature

The unit of α is $^\circ C^{-1}$.

1. For metals, α is positive i.e., resistance of metals increase with the increase in temperature.
2. For semiconductors (Ge, Si) and insulators, α is negative i.e., their resistance decreases with the increase in temperature.
3. For alloys like constantan and manganin, the temperature coefficient of resistance α is very small. So they are used for making standard resistors.

177. What do you understand by the resistivity of a conductor? Discuss its temperature dependence for a

1. Metallic conductor
2. Semiconductor
3. Ionic conductor
4. Electrolyte.

Ans : **SQP 2020**

Resistivity of a material is the resistance of a conductor of that material, having unit length and unit area of cross-section.

It is given by, $\rho = \frac{m}{ne^2\tau}$

Effect of Temperature on Resistivity

1. **Metallic Conductor :** In metals, the number of free electron is fixed. As the temperature increases, the amplitude of vibration of the atoms increases. The collisions of electrons with these atoms become more frequent. The relaxation time τ decreases. Hence the resistivity of a metallic conductor increases with the increase of temperature.
2. **Semiconductor :** In case of semiconductors, the relaxation time τ does not change with temperature but the number density of free electrons increases exponentially with the increase in temperature. Consequently, the conductivity increases or resistivity decreases exponentially with the increase in temperature.
3. **Ionic Conductor :** An ionic conductor has both positive and negative ions as the charge carriers. As the temperature increases, the electrostatic attraction between cations and anions decreases, the ions are more free to

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Let V = Potential difference between A and B.

Then, for cell ε_1,

$$V = \varepsilon_1 - I_1 r_1$$
$$I_1 = \frac{\varepsilon_1 - V}{r_1}$$

Similarly, for cell ε_2,

$$I_2 = \frac{\varepsilon_2 - V}{r_2}$$

Substituting these values in equation (1)

$$I = \frac{\varepsilon_1 - V}{r_1} + \frac{\varepsilon_2 - V}{r_2}$$

or $$I = \left(\frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{\rho_2}\right) - V\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$

Hence, V is given by,

$$V = \left(\frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2}\right) - I\left(\frac{r_1 r_2}{r_1 + r_2}\right) \quad ...(2)$$

Comparing the above equation with the equivalent circuit of emf 'ε_{eq}' and internal resistance 'r_{eq}'

$$V = \varepsilon_{eq} - I r_{eq} \quad ...(3)$$

(i) Therefore, $$\varepsilon_{eq} = \frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2}$$

(ii) $$r_{eq} = \frac{r_1 r_2}{r_1 + r_2}$$

183. The current flowing through a conductor is given by $I = neAv_d$.

(i) Identify each term in the equation.

(ii) Obtain an expression for v_d, if the current flowing through the conductor of length l has its ends maintained at a potential difference V volt.

Ans : **Main 2006, 2004**

Drifting occurs due to application of external electric field. When no external field is applied there is no drift of electrons in the conductor.

(i) The given expression is

$$I = neAv_d$$

where,

I = current flowing through the conductor

n = number of free electrons per unit volume

e = charge of an electron

A = area of cross-section

v_d = drift velocity

(ii) When a conductor of length l is subjected to the potential difference of V, each electron experiences a force

$$F = -e\frac{V}{l}$$

and free electron acquires an acceleration

$$a = \frac{F}{m} = -\frac{eE}{m} = \frac{-eV}{ml} \quad \left[\text{as, } E = \frac{V}{l}\right] \quad ...(1)$$

where, m = mass of electron, e = electronic charge and E = electric field. Free electrons starts accelerating in the conductor.

The average time difference between two consecutive collisions is known as relaxation time of electron and

$$\overline{\tau} = \frac{\tau_1 + \tau_2 + ... + \tau_n}{n} \quad ...(2)$$

where, τ_1, τ_2, ..., τ_n are the average time differences between 1st, 2nd, ..., nth collisions.

v_1, v_2, ..., v_n are velocities gained by electron in 1st, 2nd, ..., nth collisions with initial thermal velocities u_1, u_2, ... u_n respectively.

$$v_1 = u_1 + a\tau_1$$
$$v_2 = u_2 + a\tau_2$$
$$\vdots \quad \vdots \quad \vdots$$
$$v_n = u_n + a\tau_n$$

The drift speed v_d may be defined as

$$v_d = \frac{v_1 + v_2 + ... + v_n}{n}$$
$$v_d = \frac{(u_1 + u_2 + ... + u_n) + a(\tau_1 + \tau_2 + ... + \tau_n)}{n}$$
$$v_d = \frac{(u_1 + u_2 + ... + u_n)}{n} + \frac{a(\tau_1 + \tau_2 + ... + \tau_n)}{n}$$
$$v_d = 0 + a\tau \quad [\text{average thermal velocity} = 0]$$
$$v_d = -\left(\frac{eV}{ml}\right)\tau \quad [\text{from Eq. (1)}]$$

This is the required expression of drift speed of free electrons.

$$|v_d| = \frac{eV}{lm}\tau \quad \left[E = \frac{V}{l}\right]$$

184. Obtain an expression for the heat developed in a resistor by the passage of an electric current through it. Hence state Joule's law of heating.

Ans : **Main 2016**

Consider a conductor AB of resistance R, shown in figure. A source of emf maintains a potential difference V between its ends A and B and sends a steady current I from A to B.

Clearly, $V_A > V_B$ and the potential difference across AB is,

$$V = V_A - V_B > 0$$

The amount of charge that flows from A to B in time t is,

$$q = It$$

180. Derive an expression for the current density in terms of the drift speed of electrons.

Ans : **Main 2017, 2013**

Suppose a potential difference V is applied across a conductor of length l and of uniform cross-section A. The electric field E set up inside the conductor is given by

$$E = \frac{V}{l}$$

Under the influence of field $\vec{E}$, the free electrons begin to drift in the opposite direction $\vec{E}$ with an average drift velocity v_d.

Let the number of electrons per unit volume or electron density $= n$

Charge on an electron $= e$

Number of electrons in length l of the conductor

$= n \times$ volume of the conductor $= nAl$

Total charge contained in length l of the conductor is $q = enAl$

All the electrons which enter the conductor at the right end will pass through the conductor at the left end in time,

$$t = \frac{\text{distance}}{\text{velocity}} = \frac{l}{v_d}$$

Hence, Current, $I = \frac{q}{t} = \frac{enAl}{l/v_d}$

$$I = enAv_d$$

The equation relates the current I with the drift velocity v_d.

The current density j is given by,

$$j = \frac{I}{A} = env_d$$

181. Two heating elements of resistances R_1 and R_2 when operated at a constant supply of voltage V, consume powers P_1 and P_2, respectively. Deduce the expressions for the power of their combination when they are in turn, connected in

(a) Series and

(b) Parallel across their same voltage supply.

Ans : **SQP 2013**

To deduce the expression for the power of the combination, first find the equivalent resistance of the combination in the given conditions.

Since, $P_1 = \frac{V^2}{R_1} \Rightarrow R_1 = \frac{V^2}{P_1}$

and $P_2 = \frac{V^2}{R^2} \Rightarrow R_2 = \frac{V^2}{P_2}$

(a) In series combination,

$$R_s = R_1 + R_2 = \frac{V^2}{P_1} + \frac{V^2}{P_2}$$

$$R_s = V^2\left(\frac{1}{P_1} + \frac{1}{P_2}\right)$$

$$= V^2\left(\frac{P_1 + P_2}{P_1 P_2}\right)$$

Now, let the power of heating element in series combination be P_s.

Hence, $P_s = \frac{V^2}{R_1 + R_2}$

$$= \frac{V^2}{V^2\left(\frac{P_1 + P_2}{P_1 P_2}\right)}$$

$$= \frac{P_1 P_2}{P_1 + P_2} \quad ...(1)$$

(b) In parallel combination

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$= \frac{1}{\frac{V^2}{P_1}} + \frac{1}{\frac{V^2}{P_2}} = \frac{P_1}{V^2} + \frac{P_2}{V^2}$$

$$\frac{1}{R_p} = \frac{1}{V^2}(P_1 + P_2)$$

Now, power consumption in parallel combination.

$$P_p = \frac{V^2}{R_p} = V^2\left(\frac{1}{R_p}\right)$$

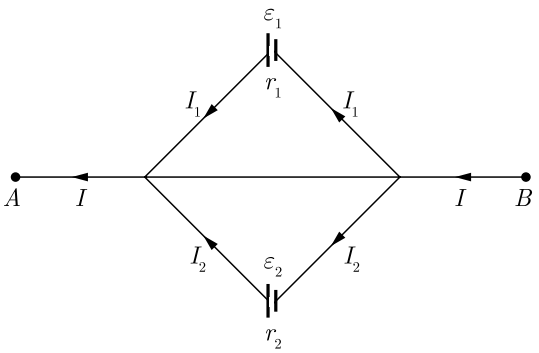
$$P_p = V^2\left[\frac{1}{V^2}(P_1 + P_2)\right]$$

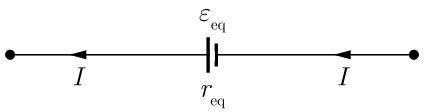
Hence, $P_p = P_1 + P_2 \quad ...(2)$

182. Two cells of emf is E_1 and E_2 internal resistance r_1 and r_2 are connected in parallel. Obtain the expression for the emf and internal resistance of a single equivalent cell that can replace this combination?

Ans : **Main 2024**

$$I = I_1 + I_2 \quad ...(1)$$





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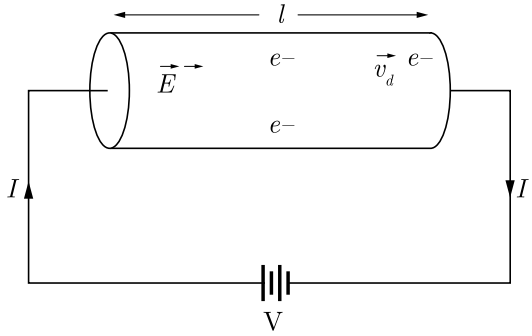
us apply a potential difference V across the ends of conductor along its length, then $E = \frac{V}{I}$



Though the free electrons in the conductor experience a force $\vec{F} = -e\vec{E}$ and thus, have an acceleration $\vec{a} = -e\frac{\vec{E}}{m}$, the drift with constant velocity $\vec{v_d}$ in the direction opposite to E.

Current I in the conductor can be written in terms of drift velocity of electrons as

$$I = ne^2 Av_d \qquad ...(1)$$

where $$v_d = \frac{eE}{m} \cdot \tau \qquad ...(2)$$

Here, τ is called the relaxation time. It is the average time interval between two successive collisions of electrons with an atom or an ion.

From equations (1) and (2),

$$I = \frac{ne^2 AE}{m} \cdot \tau$$

$$I = \frac{ne^2 A V.\tau}{ml}$$

$$\frac{V}{I} = \frac{ml}{ne^2 A\tau} = R \quad \text{(from Ohm's law)}$$

$$R = \frac{m}{ne^2\tau}\frac{l}{A}$$

$$R = \rho\frac{l}{A}, \qquad \text{where } \rho = \frac{m}{ne^2\tau}$$

Here, ρ is called the specific resistance or the resistivity of the material of conductor.

FOUR MARKS QUESTIONS

174. What is Wheatstone bridge? Explain its use in detail.

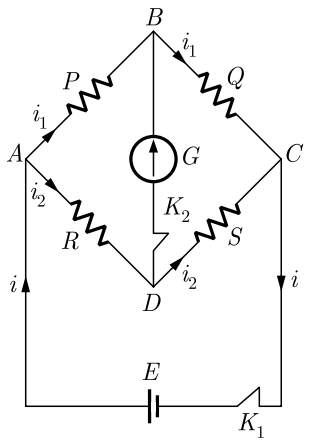
Ans : **Comp 2013, 2011**

Wheatstone bridge is an arrangement of four resistances used to determine one of these resistances quickly and accurately in terms of the remaining three resistances.

A Wheatstone bridge consists of four resistances P, Q, R and S connected to form the arms of a quadrilateral $ABCD$. A battery of emf ε is connected between points A and C and a sensitive galvanometer between B and D, as shown in Figure.

Let S be the resistance to be measured. The resistance R is so adjusted that there is no deflection in the galvanometer. The bridge is said to balanced when the potential difference across the galvanometer is zero so that there is no current through the galvanometer. In the balanced condition of the bridge,

$$\frac{P}{Q} = \frac{R}{S}$$



Unknown resistances, $S = \frac{Q}{P} \cdot R$

Knowing the ratio of resistances P and Q the resistance R, we can determine the unknown resistance S. That is why the arms containing the resistances P and Q are called ratio arms, the arm AD containing R standard arm and the arm CD containing S the unknown arm.

175. Define the terms drift velocity and relaxation time. Establish the relation between drift velocity of electrons and electric field applied to the conductor.

Ans : **Main 2019**

In the absence of any electric field, the free electrons of a metal are in a state of continuous random motion. At room temperature, their random velocities correspond to $10^5\,\text{ms}^{-1}$. The average random velocity of free electrons is zero.

$$\vec{u} = \frac{\vec{u_1} + \vec{u_2} + ... + \vec{u_N}}{N} = 0$$

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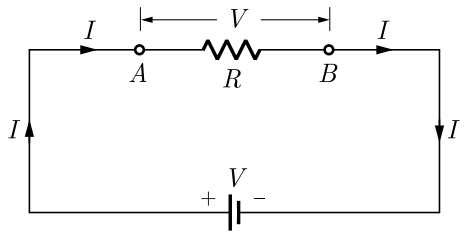


As the charge q moves through a decrease of potential of magnitude V, its potential energy decreases by the amount,

$$\begin{aligned} U &= \text{Final P. E at } B - \text{Initial P.E. at } A \\ &= qV_B - qV_A = -q(V_A - V_B) \\ &= -qV < 0 \end{aligned}$$

If the charges move through the conductor without suffering collisions, their kinetic energy would change. By conservation of energy, the change in kinetic energy must be,

$$\begin{aligned} K &= -U = qV \\ &= It \times V = VIt > 0 \end{aligned}$$

Thus, in case charges were moving freely through the conductor under the action of the electric field, their kinetic energy would increase as they move. But on the average, the electrons move with a steady drift velocity. This is because of the collisions of electrons with ions and atoms during the course of their motion. The kinetic energy gained by the electrons is shared with he metal ions. These ions vibrate more vigorously and the conductor gets heated up. The amount of energy dissipated as heat in conductor in time t is,

$$\begin{aligned} H &= VIt \text{ joule} \\ &= I^2Rt \text{ joule} = \frac{V^2t}{R}\text{joule} \\ &= \frac{VIt}{1.18}\text{cal} = \frac{I^2Rt}{4.18}\text{cal} \\ &= \frac{V^2t}{4.18R}\text{cal} \end{aligned}$$

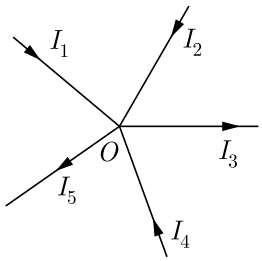
The above equations are known as joule's law of heating. According to this law, the heat produced in a resistor is,

1. Directly proportional to the square of current for a given R.
2. Directly proportional to the resistance R for a given I.
3. Inversely proportional to the resistance R for a given, V.
4. Directly proportional to the time t for which the current flows through the resistor.

185. Define Kirchhoffs laws of electrical circuit. Derive an expression for a balanced. Wheatstone's bridge using Kirchhoffs law.

Ans : **SQP 2024, 2005**

Kirchoff's Laws of Electrical Circuit : This law states that the algebraic sum of the currents meeting at a point in an electrical circuit is always zero. It is also known as junction rule.



Second Law (Kirchhoff's voltage rule) : This law states that the algebraic sum of changes in potential around any closed loop involving resistors and cells in the loop is zero. It means that in any closed part of an electrical circuit, the algebraic sum of the emfs is equal to the algebraic sum of the products of the resistances and currents flowing through them. It is also known as loop rule.

Balanced Condition of Wheatstone Bridge : In figure, four resistances P, Q, R and S connected in the four arms of a parallelogram $ABCD$. Between B and D there is a sensitive galvanometer and cell is connected between A and C. K_1 and K_2 are two keys. By pressing the key K_1, a current i is allowed to flow from the cell. At the point A, the current i is divided into two parts.

One part i_1 flows in the arm AB and the other part i_2 flows in the arm AD. The resistances P, Q, R and S are so adjusted that on pressing the key K_2 there is no deflection in the galvanometer G. That is, there is no current in the diagonal BD . Thus, the same current i_1 will flow in the arm BC as in the arm AB and the same i_2 will flow in the arm DC as in the arm AD.

Applying Kirchhoff's second law

for the closed loop $BADB$, we have

$$\begin{aligned} -i_1P + i_2R &= 0 \\ Pi_1 &= Ri_2 \qquad \ldots(1) \end{aligned}$$

Similarly, for the closed loop $CBDC$, we have

$$\begin{aligned} i_1Q + i_2S &= 0 \\ Qi_1 &= Si_2 \qquad \ldots(2) \end{aligned}$$

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One part I_1 flows in the arm AB and the other part I_2 flows in the arm AD. The resistances P, Q, R and S are so adjusted that there is no deflection in the galvanometer G. i.e., there is no current in the diagonal BD . Thus, the same current I_1 will flow in the arm BC as in the arm AB and the same I_2 will flow in the arm DC as in the arm AD.

Applying Kirchhoff's second law for the closed loop $BADB$, we have

$$PI_1 = RI_2 \quad ...(1)$$

Similarly, for the closed loop $CBDC$, we have

$$QI_1 = SI_2 \quad ...(2)$$

Dividing Eq. (1) by Eq. (2), we get

$$\frac{I_1P}{I_1Q} = \frac{I_2R}{I_2S}$$

or

$$\frac{P}{Q} = \frac{R}{S}$$

170. n cells, each of emf e and internal resistance r are joined in the series to form a row m such rows are connected in parallel to form a battery of $N = mn$ cells. This battery is connected to an external resistance R.

(i) What is the emf of this battery and how much is its internal resistance?

(ii) Show that current I flowing through the external resistance R is given by

$$I = \frac{Ne}{mR + nr}$$

Ans : **Main 2013, 2009**

In mixed grouping of cells the equivalent emf can be calculated by first calculating emf for the series combination and then find equivalent emf for the parallel combination. Let E_1, E_2, ..., E_n are emf's and r_1, r_2, ... r_n are the internal resistance of n cells.

(i) For I cell, $E_1 = V_1 + ir_1$

$$V_1 = E_1 - ir_1$$

For II cell, $V_2 = E_2 - ir_2$

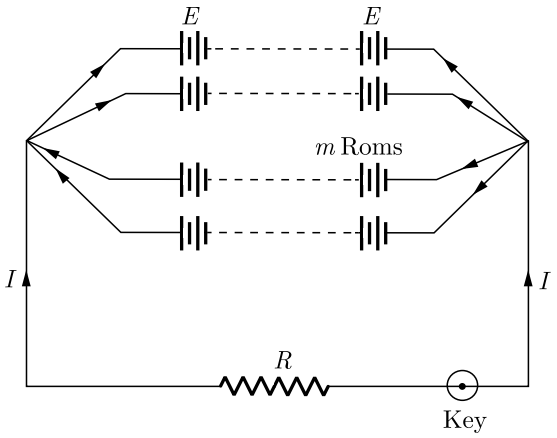
For n th cell, $V_n = E_n - ir_n$

Total voltage difference

$$V = V_1 + V_2 + V_3 + ... + V_n$$

$$V = (E_1 + E_2 + ... + E_n) - i(r_1 + r_2 + ... + r_n)$$

$$V = E_{eq} - ir_{eq}$$



where, $E_{eq} = E_1 + E_2 + ... + E_n$

$$r_{eq} = r_1 + r_2 + ... + r_n$$

If $E_1 = E_2 = ... = E_n = E$

and $r_1 = r_2 = ... = r_n = r$

Then, $E_{eq} = nE \Rightarrow r_{eq} = nr$

If m rows of series of n cells are connected in parallel, then

Total emf of battery i.e., equivalent emf $= nE$

Total internal resistance

$$= \frac{nr}{m}$$

(ii) The electric current flow in the circuit

$$I = \frac{\text{Total emf}}{\text{Total resistance}}$$

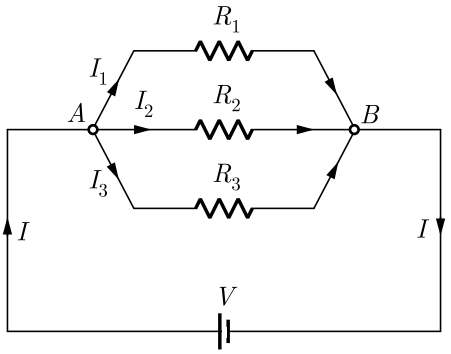
$$I = \frac{nE}{\frac{nr}{m} + R} = \frac{mnE}{nr + mR}$$

According to the questions, $E = e$

$$I = \frac{mne}{mR + nr} = \frac{Ne}{mR + nr} \quad [N = mn]$$

171. Three resistances R_1, R_2 and R_3 are connected in parallel. Find the equivalent resistance of the parallel combination.

Ans : **Main 2018**



Resistances in Parallel

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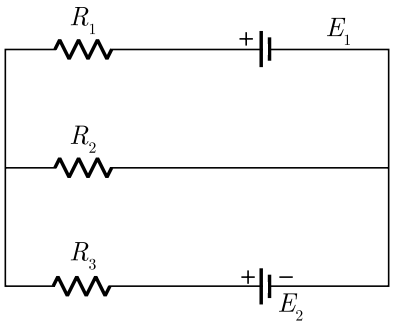
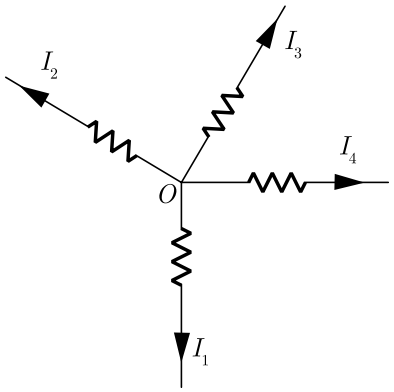


Ans : **Main 2000**

Kirchhoff has given two rules based on conservation of electric charge and of energy these are known as Kirchhoff's laws.



Kirchhoff s first law or junction rule The algebraic sum of electric currents at any junction of electric circuit is equal to zero i.e., the sum of current entering into a junction is equal to the sum of current leaving the junction, i.e.

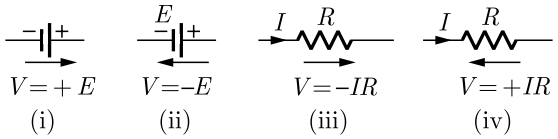
$$\Sigma I = 0,\ I_4 = I_1 + I_2 + I_3$$

Junction law supports law of conservation of charge, because this is a point in circuit which cannot act as a source or sink of charge(s).

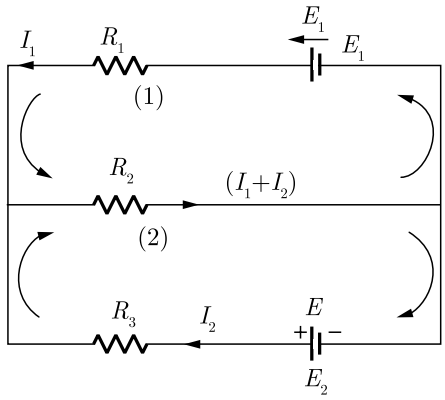
Kirchhoff s second law or voltage rule In any closed mesh of electrical circuit, the algebraic sums of emf of cell and the product of currents and resistance is always equal to zero i.e.,

$$\Sigma E + \Sigma IR = 0$$

Kirchhoff's second law supports the law of conservation of energy. Because the net change in the energy of a charge, after the charge complete a closed path must be zero.



Consider the circuit diagram shown below. The second law can be expressed as, $\Sigma E + \Sigma IR = 0$



As given in the diagram, applying this law for mesh (1)

For mesh or loop (1),

$$-I_1R_1 - (I_1 + I_2)R_2 = E_1 = 0$$
$$I_1R_1 + (I_1 + I_2)R_2 = E_1$$

For mesh (2),

$$-I_2R_3 - (I_1 + I_2)R_2 + E_2 = 0$$
$$I_2R_3 + (I_1 + I_2)R_2 = E_2$$

188. What are ohmic and non-ohmic conductors/ resistors? State the conditions under which Ohm's law is not obeyed. Give one example of each type.

Ans : **SQP 2019**

Ohmic Conductors : The conductors which obey Ohm's law are called ohmic conductors. For these conductors, $V - I$ graph is a straight line passing through the origin. For example, a metallic conductor for small currents is an ohmic conductor, as shown in the $V-I$ graph of Figure.

Non-ohmic Conductors : The conductors which do not obey Ohm's law are called non-ohmic conductors. The non-ohmic situations may be of the following types :

1. $V-I$ **relationship is non-linear**. When a large current flows through a metallic conductor, it gets heated up and its resistance increases. The $V-I$ graph becomes non-linear i.e., the conductor becomes non-ohmic at higher currents, as shown in Figure.

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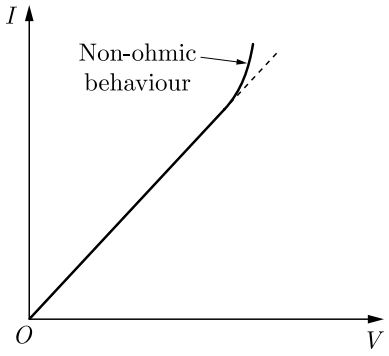
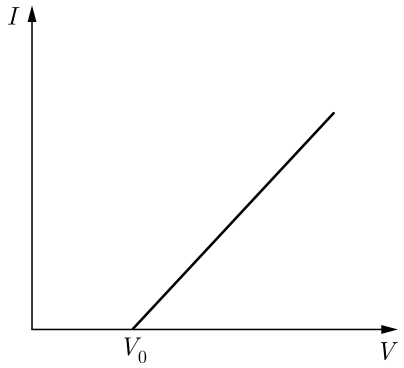


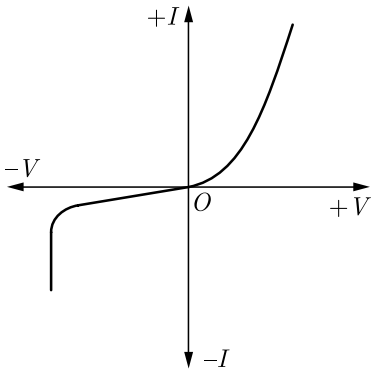
V-I **Graph for Metallic Conductor**

2. The straight line $V-I$ graph does not pass through the origin. The $V-I$ graph for a water voltmeter is a straight line but not passing through the origin, as shown in Figure. So the electrolyte (water acidified with dil. H_2SO_4) is a non-ohmic conductor.



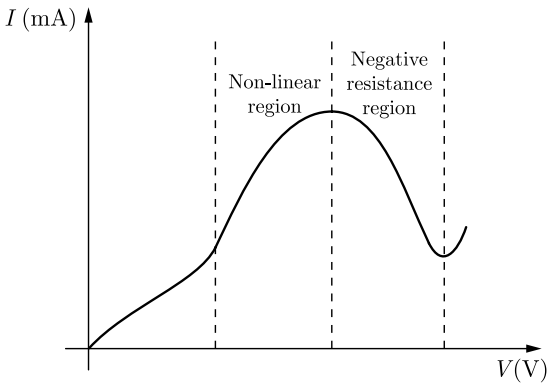
V-I **Graph for a Water Voltmeter**

3. $V-I$ relationship depends on the sign of V for the same absolute value of V. I is the current for a certain V, then reversing the direction of V keeping its magnitude fixed, does not produce a current of same magnitude as I in the opposite direction, as shown in the $V-I$ graph for a junction diode in figure.



V-I **Graph for a Junction Diode**

4. $V-I$ relationship is non-unique. Figure shows the $V-I$ graph for the semiconductor GaAs. It exhibits non-linear behaviour i.e., there is more than one value of V for the same current I.



V-I **Graph for GaAs**

NUMERICAL QUESTIONS

189. A 2 V battery with internal resistance of $0.1\,\Omega$ is charged with a current of 5 A. Calculate the potential difference between the terminals of the battery.

Ans : **Main 2005**

Given, $E = 2\,\text{V}$, $i = 5\,\text{A}$, $r = 0.1\,\Omega$

Terminal voltage when a cell is charging is

$$V = E + ir = 2 + 5 \times 0.1$$
$$= 2 + 0.5 = 2.5\,\text{V}$$

190. The potential difference applied across a given resistor is altered so that heat produced per second increase by a factor of 9. By what factor does the applied potential difference change?

Ans : **Main 2017**

Heat increase 9 factor, so current increased by 3 factor, so potential increased by 3 factor.

also, $$H = \frac{V^2}{R}t$$
$$H \propto V^2$$

H increased by factor, so V increased by factor 3.

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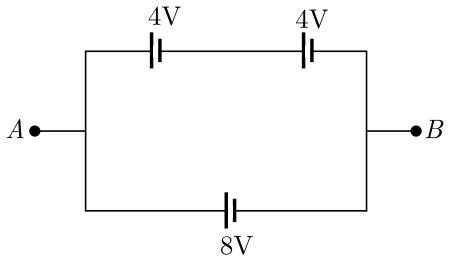
191. Calculate the net emf across A and B as shown in the figure below



Ans : **Main 2019, 2017**

4 V and 4 V cells are in series so their combined emf, $E_1 = 4 + 4 = 8\,\text{V}$. Now E_1 and 8 V cells are in parallel, so the combined emf of the battery is 8 V.

192. In a potentiometer experiment, balancing length is found to be 120 cm for a cell ε_1 of emf 2 V. What will be the balancing length for another cells ε_2 of emf 1.5 V? No other changes are made in the experiment.

Ans : **Main 2018**

If l_1 and l_2 are the balancing lengths corresponding to emfs ε_1 and ε_2, then

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{l_1}{l_2}$$

$$\frac{2}{1.5} = \frac{120}{l_2}$$

$$\text{Balancing length, } l_2 = \frac{120 \times 1.5}{2} = 90\,\text{cm}$$

193. A 10 m long potentiometer wire carries a steady current. A standard cell of emf 1.018 V is balanced against a length of 254.5 cm of the wire. What is the potential gradient across the potentiometer wire?

Ans : **Main 2011**

$$l = 254.5\ \text{cm},\ E = 1.018\ \text{V}$$

where, E = emf of the cell

l = balancing length

$$\text{Potential gradient } k = E/l$$

$$= \frac{1.018}{254.5} = 0.004\,\text{V/cm}$$

194. A metallic wire has a resistance of $3.0\,\Omega$ at 0°C and $4.8\,\Omega$ at 150°C. Find the temperature coefficient of resistance of its material.

Ans : **Main 2016**

At temperature $t_0(0^\circ\text{C})$, resistance $R_0 = 3\,\Omega$

At temperature $t(150^\circ\text{C})$ resistance $R_t = 4.8\,\Omega$

Temperature coefficient of resistance,

$$\alpha = \frac{R_t - R_0}{R_0 \times \Delta t}$$

$$\alpha = \frac{4.8 - 3.0}{3 \times 150} \qquad [\Delta t = 150 - 0]$$

$$\alpha = \frac{1.8}{3 \times 150} = \frac{0.6}{150}$$

$$= \frac{6}{1500} = \frac{2}{500}$$

$$\alpha = 0.004\,^\circ\text{C}^{-1}$$

195. In a potentiometer experiment, the balancing length with a resistance of $2\,\Omega$ is found to be 100 cm, while that of an unknown resistance is 500 cm. Calculate the value of the unknown resistance.

Ans : **Main 2025**

If l_1 and l_2 are the balancing lengths corresponding to resistance R and X respectively,

$$\frac{X}{R} = \frac{l_2}{l_1}$$

Unknown resistance,

$$X = \frac{l_2}{l_1}R = \frac{500}{100} \times 2$$

$$X = 10\,\Omega$$

196. The maximum power dissipated in a $10000\,\Omega$ resistor is 10 W. What is the maximum current?

Ans : **Main 2001**

Given,

$$\text{Maximum power} = 10\,\text{W},$$

$$\text{Resistance} = 10000\,\Omega$$

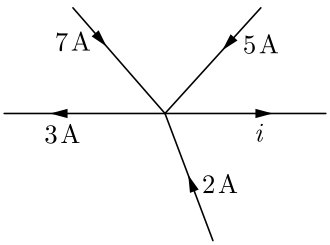
Since, $P = i^2 R$

$$i^2 = \frac{P}{R} = \frac{10}{10000}$$

$$= \frac{1}{1000}$$

$$i = \frac{1}{10\sqrt{10}} = 0.0316\,\text{A}$$

197. What is the value of i in the given circuit?



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$$E = 200 - 10 = 190 \text{ Volt}$$

Hence, the current in circuit,

$$I = \frac{E}{R} = \frac{190}{38} = 5\text{A}$$

208. A platinum wire has a resistance of $10\,\Omega$ at 0° C and $20\,\Omega$ at 273° C. What is value of temperature coefficient of resistance of platinum?

Ans : **Comp 2018**

Resistance of wire at 0° C, $R_0 = 10\,\Omega$

Initial temperature, $T_1 = 0^\circ$ C

Resistance of wire at 273° C, $R_{273} = 20\,\Omega$

Final temperature, $T_2 = 273^\circ$ C

We know that resistance of wire at 273° C,

$$R_{273} = R_0[1 + \alpha(T_2 + T_1)]$$

$$20 = 10[1 + \alpha(273 - 0)]$$

$$= 10 + 2730\alpha$$

or, $$\alpha = \frac{20 - 10}{2730}$$

$$= \frac{10}{2730}$$

$$= 0.0037^\circ\text{C}^{-1}$$

where, α = Temperature coefficient of resistance of platinum

209. A current is passed through two coils connected in series. The potential difference across the first coil is 3 V and that of the second coil is 4.5 V. If the first coil has a resistance of $2\,\Omega$, what is the resistance of second coil?

Ans : **Main 2020**

Potential difference across first coil,

$$V_1 = 3 \text{ Volt}$$

Potential difference across second coil,

$$V_2 = 4.5 \text{ Volt}$$

And resistance of first coil,

$$R_1 = 2\,\Omega$$

We know that current across the coils in series,

$$I = \frac{V_1}{R_1}$$

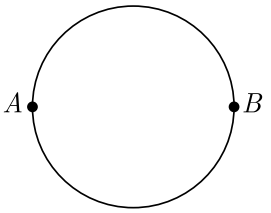
$$= \frac{3}{2} = 1.5\text{ A}$$

Therefore resistance of second coil,

$$R_2 = \frac{V_2}{I}$$

$$= \frac{4.5}{1.5} = 3\,\Omega$$

210. A wire of resistance $4R$ is bent in the form of a circle as shown in the figure. What is the effective resistance between the opposite ends A and B of the circle?



Ans : **Main 2017, 2013**

Resistance of wire $= 4R$

We know that as the wire has a resistance of $4R$, therefore when it is bent in the from of a circle, then it will behave as a combination of two wires each of resistance $2R$ connected in parallel combination between A and B.

Therefore effective resistance between the ends A and B of the circle,

$$R_{AB} = \frac{2R \times 2R}{2R + 2R} = R$$

211. A series combination of two resistors $1\,\Omega$ each is connected to a 12 V battery of internal resistance $0.4\,\Omega$. what is the value of current flowing through it?

Ans : **SQP 2017**

Given,

Resistance of each resistor, $R = 1\,\Omega$

Voltage of battery, $V = 12$ Volt

Internal resistance of battery, $r = 0.4\,\Omega$

Since both the resistance are connected in a series combination, therefore total external resistance,

$$R' = 1 + 1 = 2\,\Omega$$

Thus total resistance of the circuit,

$$R = R' + r$$

$$= 2 + 0.4 = 2.4\,\Omega$$

And current flowing through the circuit,

$$I = \frac{V}{R} = \frac{12}{2.4} = 5\text{ A}$$

212. A uniform copper wire having a cross-sectional area of 1 mm^2 carries a current of 5 A. Calculate the drift speed of free electrons in it. (Free electron number density of copper $= 2 \times 10^{28}/\text{m}^3$)

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203. A galvanometer with a resistance of 75 Ω produces a full scale deflection with a current of 5 mA. How can this galvanometer be converted into an ammeter which has a range of 0-5 A?

Ans : **Main 2011**

Given, $i_g = 5\,\text{mA} = 5 \times 10^{-3}\,\text{A} = 0.005\,\text{A}$

$i = 5\,\text{A},\ G = 75\,\Omega$

$i_g =$ galvanometer current

$G =$ galvanometer resistance

$i =$ net current

Shunt resistance,

$$S = \left(\frac{i_g}{i - i_g}\right)G$$

$$= \left(\frac{5 \times 10^{-3}}{5 - 0.005}\right) \times 75 = 0.075\,\Omega$$

By adding a shunt resistance of 0.075 Ω a galvanometer can be converted to ammeter having range 0.5 A.

204. A cell of e.m.f. 1.5 V is connected with an ammeter of resistance 0.05 Ω. If the current in the circuit is 2.0 A, what is the internal resistance of the cell ?

Ans : **SQP 2019, 2014**

E.m.f. of cell, $E = 1.5\,\text{Volt}$

Resistance of ammeter,

$$R = 0.05\,\Omega$$

Current in circuit, $I = 2.0\,\text{A}$

$$I = \frac{E}{R + r}$$

where, $r =$ internal resistance of cell

Hence, $$I = \frac{E}{R + r}$$

$$2.0 = \frac{1.5}{0.05 + r}$$

$$2.0(0.05 + r) = 1.5$$

$$0.1 + 2r = 1.5$$

$$2r = 1.4$$

$$r = 0.7\,\Omega$$

205. When a potential difference of 3 V is applied between the two ends of a 60 cm long metallic wire, current density in it is found to be $1 \times 10^{-7}\,\text{Am}^{-2}$. Find conductivity of the material of the wire in SI system.

Ans : **Main 2012**

We have to apply Ohm's law for current density

$$\vec{J} = \sigma\vec{E}$$

Potential difference

$$V = 3\,\text{Volt},$$

Length, $l = 60\,\text{cm} = 0.6\,\text{m},$

Current density,

$$J = 1 \times 10^{-7}\,\text{Am}^{-2}$$

Conductivity, $\sigma = \frac{J}{E} = \frac{J \cdot l}{V}$

$$= \frac{1 \times 10^{-7} \times 0.6}{3}$$

$$= 2 \times 10^{-8}(\Omega - \text{m})^{-1} \quad \left[\text{as, } E = \frac{V}{l}\right]$$

206. Three bulbs of specifications 60 W/220 V, 100 W/220 V and 1000 W/220 V are connected in series. Which one will glow the brightest?

Ans : **Main 2024, 2002**

Resistance is given by

$$R = \frac{V^2}{P}$$

$$\text{R}_1\ (60\ \text{W bulb}) = (220)^2/60$$

$$= 48400/60 = 806.67\ \Omega$$

$$\text{R}_2\ (100\ \text{W bulb}) = (220)^2/100$$

$$= 48400/100 = 484\ \Omega$$

$$\text{R}_3\ (1000\ \text{W bulb}) = (220)^2/1000$$

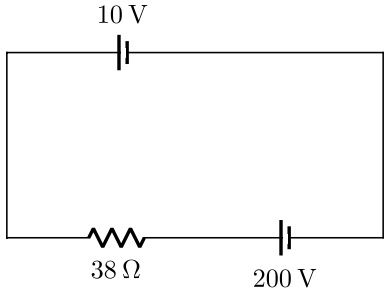
$$= 48400/1000 = 48.4\ \Omega$$

Since in series, power consumed $P = I^2R$,

The bulb with the highest resistance will glow the brightest. The 60 W bulb has the highest resistance (806.67 Ω).

Therefore ,the 60 W bulb will glow the brightest in series connection.

207. A 10 V battery of negligible internal assistance is connected across a 200 V battery and a resistance of 38 Ω as shown in the figure. Find the value of the current circuit.



Ans : **SQP 2021**

Since, the positive terminal of the batteries are connected together, so the equivalent emf of the batteries

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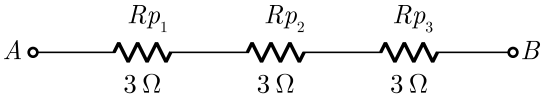


$$R_S = R_{P1} + R_{P2} + R_{P3}$$
$$= 3 + 3 + 3 = 9\,\Omega$$

225. A wire 50 cm long and $1\,\text{mm}^2$ in cross-section carries a current of 4 A when connected to a 2 V battery. What is the specific resistivity of the wire?

Ans : SQP 2013

Given,

Length of wire, $l = 50\,\text{cm} = 0.5\,\text{m}$

Cross-sectional area of wire

$$A = 1\,\text{mm}^2 = 10^{-6}\,\text{m}^2$$

Current in wire, $I = 4\,\text{A}$

Voltage of battery, $V = 2\,\text{Volt}$

We know that, resistance of the wire

$$R = \frac{V}{I} = \frac{2}{4} = 0.5\,\Omega$$

We also know that resistance of the wire,

$$R = \rho \times \frac{l}{A}$$

or,
$$\rho = \frac{R \times A}{l}$$
$$= \frac{0.5 \times 10^{-6}}{0.5}$$
$$= 1 \times 10^{-6}\,\Omega\text{-m}$$

Where, ρ = Specific resistivity of the wire

226. The resistance of series combination of two equal resistances is S. When they are joined in parallel, the total resistance is P. If $S = nP$, What is the possible value of n ?

Ans : Main 2015

First resistance, $R_1 = R$

Second resistance, $R_2 = R$

Equivalent resistance of two resistances, when they are joined in series $= S$ and equivalent resistance of two resistances, when they are joined in parallel $= P$.

and $S = nP$

We know that equivalent resistance of two resistances when they are joined in series,

$$S = R_1 + R_2$$
$$= R + R = 2R$$

Similarly, equivalent resistance of two resistances when they are joined in parallel,

$$P = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{R \times R}{R + R} = \frac{R}{2}$$

Since, $S = nP$

Therefore, $2R = n \times \frac{R}{2}$

or $n = 4$

227. A uniform wire of resistance R and length L is cut into four equal parts, each of length $\frac{L}{4}$, which are then connected in parallel combination. What will be effective resistance of the combination?

Ans : SQP 2009

Resistance of single wire, $R_1 = R$

Length of single wire, $l_1 = L$

Length of each part, $l_2 = \frac{L}{4}$

We know that resistance of the wire,

$$R = \rho \times \frac{l}{A} \propto l$$

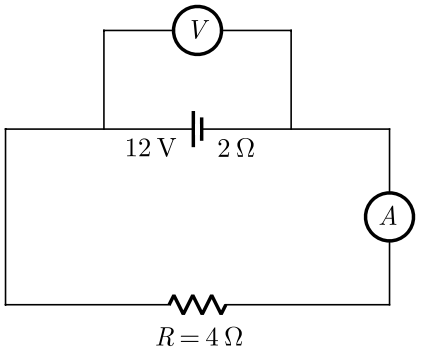
Therefore, $\frac{R_1}{R_2} = \frac{l_1}{l_2} = \frac{L}{\frac{L}{4}} = 4$

or, $R_2 = \frac{R_1}{4} = \frac{R}{4}$

We also know that relation for the effective resistance of the parallel combination is,

$$\frac{1}{R_{eff}} = \left(\frac{1}{\frac{R}{4}} + \frac{1}{\frac{R}{4}} + \frac{1}{\frac{R}{4}} + \frac{1}{\frac{R}{4}}\right)$$
$$= \left(\frac{4}{R} + \frac{4}{R} + \frac{4}{R} + \frac{4}{R}\right) = \frac{16}{R}$$
$$R_{eff} = \frac{R}{16}$$

228. In the figure shown, an ammeter A and a resistor of $4\,\Omega$ are connected to the terminals of the source. The emf of the source is 12 V having an internal resistance of $2\,\Omega$. Calculate the voltmeter and ammeter readings.



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Ans : **Main 2020**

Cross-sectional area of a copper wire,

$$A = 1\,\text{mm}^2 = 1 \times 10^{-6}\,\text{m}^2,$$

Current, $I = 5\,\text{A}$

Free electron number density,

$$n = 2 \times 10^{28}/\text{m}^3$$

Drift velocity, $v_d = ?$

$$I = nAev_d$$

$$v_d = \frac{I}{neA}$$

$$= \frac{5}{2 \times 10^{28} \times 1.6 \times 10^{-19} \times 1 \times 10^{-6}}$$

$$= 1.56 \times 10^{-3}\,\text{ms}^{-1}$$

213. A galvanometer with a coil of resistance $100\,\Omega$ and a scale having 100 divisions has a current sensitivity of $25\,\mu\text{A}$/division. How will you convert it into an ammeter of range 0 to 5 A?

Ans : **Main 2008**

Resistance of the galvanometer

$$G = 100\,\Omega,\ i_g = 100 \times 25\,\mu\text{A} = 0.0025\,\text{A}$$

Shunt resistance is given by

$$S = \left(\frac{i_g}{i - i_g}\right)G \qquad [i = 5\,\text{A}]$$

Where,

$i_g =$ galvanometer current

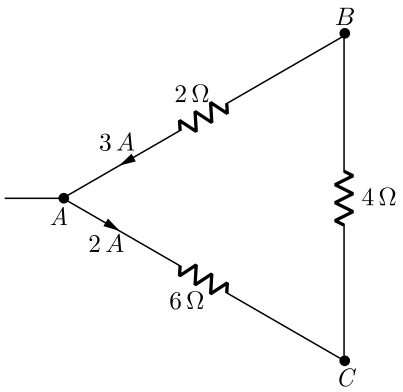
$G =$ galvanometer resistance

$i =$ current to which shunt resistance is to added

$$= \frac{2.5 \times 10^{-3}}{5 - 0.0025} \times 100$$

$$S \approx 0.05\,\Omega \qquad \text{[in parallel]}$$

214. A part of an electric circuit is shown below.



Using Kirchhoff s 2nd law, find the current I flowing through the $4\,\Omega$ resistor.

Ans : **Main 2010**

Applying Kirchhoff's 2nd law in the given loop $ABCA$, i.e., net voltage across this loop must be equals to zero.

$$-3 \times 2 - I \times 4 + 6 \times 2 = 0$$

$$-6 - 4I + 12 = 0$$

$$4I = 6$$

$$I = \frac{6}{4} = 1.5\,\text{A}$$

215. A bulb rated 100 W, 220 V is connected across 240 Volt. Calculate electrical power loss.

Ans : **Main 2025**

Power of Bulb, $P = 100\,\text{W}$

Voltage of bulb $= 220\,\text{Volt}$

Resistance of bulb, $R = \frac{V^2}{P}$

$$= \frac{(220)^2}{100}$$

$$= \frac{220 \times 220}{100} = 484\,\Omega$$

Now, $P = \frac{V^2}{R}$

$V = 240\,\text{volt}$

$$P = \frac{(240)^2}{484} = 119.00\,\text{W}$$

216. A wire of resistance $16\,\Omega$ is elongated to double its length. Find the new resistance.

Ans : **SQP 2016, 2014**

Resistance of wire, $R = 16\,\Omega$

$$R = \frac{\rho l}{A} \qquad \ldots(1)$$

When wire is elongated to double its length. Its volume remains constant.

Volume of wire before elongation

$=$ Volume of wire after elongation

$$Al = A'l'$$

Here, $l' = 2l$

$$Al = A'(2l)$$

$$A' = \frac{A}{2}$$

Now, $R' = \frac{\rho l'}{A'} = \frac{\rho(2l)}{\frac{A}{2}} = 4\left(\frac{\rho l}{A}\right)$

$$= 4R \qquad \text{(From Eq. 1)}$$

$$= 4 \times 16 = 64\,\Omega$$

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217. When 5 V potential difference is applied across a wire of length 0.1 m, the drift speed of electron is 2.5×10^{-4} m/s. If the electron density in the wire is $8 \times 10^{28}\,\text{m}^{-3}$, calculate the resistivity of the material of wire.

Ans : **Main 2015**

We know that,

$$I = neAv_d$$

$$I = \frac{V}{R}$$

and $$R = \rho\frac{l}{A}$$

So, $$\frac{V}{R} = neAv_d$$

$$\frac{V}{nev_d l} = \frac{RA}{l}$$

$$\rho = \frac{V}{nev_d l}$$

$$\rho = \frac{5}{8 \times 10^{28} \times 1.6 \times 10^{-19} \times 2.5 \times 10^{-4} \times 0.1}\,\Omega\text{-m}$$

$$= 1.56 \times 10^{-5}\,\Omega\text{-m}$$

$$\approx 1.6 \times 10^{-5}\,\Omega\text{-m}$$

218. A moving coil galvanometer has a coil of resistance $59\,\Omega$. It shows a full scale deflection for a current of 50 mA. How will you convert it to an ammeter having a range of 0 to 3 A?

Ans : **SQP 2015**

Given, $R = 59\,\Omega$

According to the formula,

$$S = \left(\frac{I_g}{I - I_g}\right)G$$

$$G = 59\,\Omega$$

$$I_g = 50\,\text{mA} = 50 \times 10^{-3}\,\text{A}$$

$$I = 3\,\text{A}$$

Shunt resistance $$S = \frac{I_g G}{I - I_g}$$

$$= \frac{50 \times 10^{-3} \times 59}{(3 - 50 \times 10^{-3})}$$

$$= \frac{50 \times 59}{1000 \times \frac{59}{20}}$$

$$= \frac{50 \times 59 \times 20}{1000 \times 59}$$

$$= 1\,\Omega$$

Hence, to convert galvanometer into ammeter, a shunt of $1\,\Omega$ is connected in parallel with the galvanometer.

219. In a Wheatstone's bridge, all the four arms have equal resistance R. If resistance of the galvanometer arm is also R, What is the equivalent resistance of the combination?

Ans : **Main 2013**

Resistances in four arms,

$$R_1 = R_2 = R_3 = R_4 = R$$

and Resistance of galvanometer,

$$G = R$$

We know that in a Wheatstone bridge, the resistance of galvanometer is ineffective.

Now resistances in upper arms are in a series combination. Therefore, their equivalent resistance,

$$R_U = R_1 + R_2 = R + R = 2R$$

Similarly, equivalent resistance of lower arms,

$$R_L = R_3 + R_4 = R + R = 2R$$

Now the equivalent resistance R_U and R_L are in parallel combination. Therefore, equivalent resistance of the combination,

$$R_{eq} = \frac{R_U \times R_L}{R_U + R_L} = \frac{2R \times 2R}{2R + 2R} = R$$

220. Two cells of emfs 1.5 V and 2.0 V having internal resistance $0.2\,\Omega$ and $0.3\,\Omega$ respectively are connected in parallel. Calculate the emf and internal resistance of the equivalent cell.

Ans : **SQP 2012, 2009**

Given, $E_1 = 1.5$ Volt, $r_1 = 0.2\,\Omega$,

$E_2 = 2.0$ Volt $r_2 = 0.3\,\Omega$

Emf of equivalent cell,

$$E = \frac{\frac{E_1}{r_1} + \frac{E_2}{r_2}}{\frac{1}{r_1} + \frac{1}{r_2}}$$

$$= \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}$$

$$= \left(\frac{1.5 \times 0.3 + 2 \times 0.2}{0.2 + 0.3}\right)$$

$$= \frac{0.45 + 0.40}{0.5} = 1.7\,\text{Volt}$$

Internal resistance of equivalent cell,

$$\frac{1}{r} = \frac{1}{r_1} + \frac{1}{r_2} = \frac{r_1 r_2}{r_1 + r_2}$$

$$= \left(\frac{0.2 \times 0.3}{0.2 + 0.3}\right)\Omega$$

$$= \frac{0.06}{0.5}\,\Omega$$

$$= 0.12\,\Omega$$

NODIA

221. At room temperature, copper has free electron density of $8.4 \times 10^{28}\,\text{m}^{-3}$. What will be drift velocity of electron in a copper conductor of cross-sectional area of $10^{-6}\,\text{m}^2$ and carrying a current of 5.4 A ?

Ans : **Comp 2020**

Electron density, $n = 8.4 \times 10^{28}\,\text{m}^{-3}$

Cross-sectional area of conductor,

$$A = 10^{-6}\,\text{m}^2$$

Current, $I = 5.4\,\text{A}$

We know that drift velocity of free electrons in a copper conductor,

$$V_d = \frac{I}{neA}$$

where, e = Charge on an electron equal to $1.6 \times 10^{-19}\,\text{C}$)

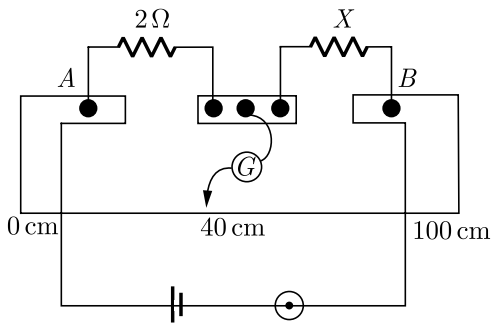
$$= \frac{5.4}{(8.4 \times 10^{28}) \times (1.6 \times 10^{-19}) \times 10^{-}}$$

$$= \frac{5.4}{8.4 \times 1.6 \times 10^{3}}$$

$$= 0.4 \times 10^{-3}\,\text{m-s}^{-1}$$

$$= 0.4\,\text{mm-s}^{-1}$$

222. In figure given below, find the value of resistance X for which points A and B are at the same potential.



Ans : **Main 2016**

Applying the Wheatstone bridge condition (balanced)

$$\frac{R}{X} = \frac{l}{100 - l}$$

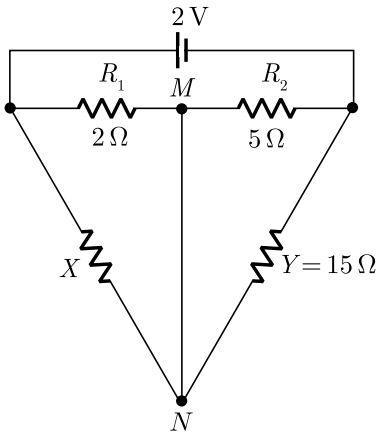
$$R = 2\,\Omega \;\; X = ?,\; l = 40\,\text{cm}$$

$$\frac{2}{X} = \frac{40}{100 - 40}$$

$$\frac{2}{X} = \frac{40}{60}$$

$$X = \frac{2 \times 60}{40} = 3\,\Omega$$

223. Find the value of resistance X in the circuit below so that the junctions M and N are at the same potential.



Ans : **Main 2009**

For balanced condition of Wheatstone bridge,

$$\frac{P}{Q} = \frac{R}{S}$$

$$\frac{R_1}{R_2} = \frac{X}{Y}$$

$$\frac{2}{5} = \frac{X}{15}$$

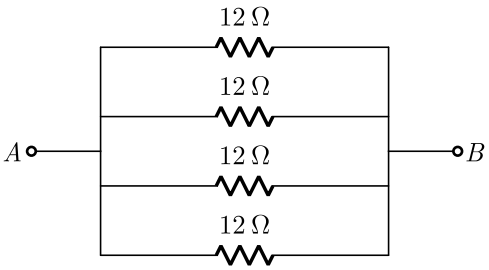
$$X = 6\,\Omega$$

Where P, Q, R and S are arm resistances of the Wheatstone bridge.

224. Four 12 Ω resistance are connected in parallel. Three such combinations are connected in series. What will be the total resistance?

Ans : **Comp 2018**

Four 12 Ω resistance are connected in the parallel combination as shown in figure.



Now,

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$$

$$= \frac{1}{12} + \frac{1}{12} + \frac{1}{12} + \frac{1}{12}$$

$$R_P = \frac{12}{4} = 3\,\Omega$$

Three such combination are connected in series as shown in the figure,

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Ans : **Main 2017, 2006**

Apply the KCL at junction A, we get

$$7+5+2-3-i = 0$$
$$14-3-i = 0$$
$$i = 11\,\text{A}$$

198. Two copper wires are of the same length. One wire is twice as thick as the other. What is the resistances of the two wires are in the ratio ?

Ans : **Main 2010**

Length of each wire $= l$

Thickness of first wire, $r_1 = r$

Thickness of second wire, $r_2 = 2r$

We know that the resistance of the wire,

$$R = \rho \times \frac{l}{A}$$
$$= \rho \times \frac{l}{\pi r^2} \propto \frac{1}{r^2}$$

Therefore, $\frac{R_1}{R_2} = \left(\frac{r_2}{r_1}\right)^2$

$$= \left(\frac{2r}{r}\right)^2 = \frac{4}{1}$$

199. An electric bulb is marked 200 V, 100 W. Calculate electrical resistance of its filament. If five such bulbs are connected in series to a 200 V supply, how much current will flow through them?

Ans : **Main 2018**

Power, $P = \frac{V^2}{R}$

Resistance, $R = \frac{V^2}{P} = \frac{(200)^2}{100}$

$$= \frac{200 \times 200}{100} = 400\,\Omega$$

When five bulbs are joined in series, the same current will flow through the each bulb.

Current, $i = \sqrt{\frac{P}{R}}$

$$i = \sqrt{\frac{100}{400}}$$
$$i = \frac{1}{2} = 0.5\,\text{A}$$

200. A bulb of 220 volt and 300 watt is connected across 110 volt circuit. What is the percentage reduction in power?

Ans : **SQP 2019**

Voltage of bulb, $V = 220$ Volt

Power of bulb, $P = 300$ W

Supply voltage, $V_S = 110$ Volt

We know that resistance of bulb,

$$R = \frac{V^2}{P} = \frac{(220)^2}{300} = \frac{484}{3}\,\Omega$$

We also know that power of the bulb,

$$P' = \frac{(V_S)^2}{R} = \frac{(110)^2}{484/3} = 75\,\text{W}$$

Therefore percentage reduction is power,

$$P'' = \frac{P-P'}{P}$$
$$= \frac{300-75}{300} = 75\%$$

NODIA

201. Calculate the electric current density in a uniform wire connected to a battery of emf 3.5 V and negligible internal resistance. The resistance of the wire is 2.0 Ω and its area of cross-section is $0.70 \times 10^{-6}\,\text{m}^2$.

Ans : **Main 2007**

Given, $R =$ resistance of wire $= 2\,\Omega$

$A =$ Area of cross-section

$= 0.70 \times 10^{-6}\,\text{m}^2$

$E =$ Voltage of battery $= 3.5$ V

$r =$ Internal resistance $= 0$

$$i = \frac{E}{R+r} = \frac{3.5}{2+0} = 1.75\,\text{A}$$

$$J = \frac{i}{A}$$

$$J = \frac{1.75}{0.70 \times 10^{-6}} = 2.50 \times 10^6\,\text{A/m}^2$$

202. An electric bulb is rated as 250 V, 750 W. Calculate the

(i) electric current flowing through it, when it is operated on a 250 V supply and

(ii) resistance of its filament.

Ans : **Main 2024**

(i) Given,

Voltage, $V = 250$ Volt

and power, $P = 750$ W

Power, $P = VI$

$$750 = 250 \times I$$

Current, $I = \frac{750}{250} = 3\,\text{A}$

(ii) Now, from Ohm's law,

$$V = IR$$
$$R = \frac{V}{I} = \frac{250}{3} = 83.33\,\Omega$$

Hence, resistance of filament $= 83.33\,\Omega$

Ans : **SQP 2014**

$$I = \frac{V}{R} = \frac{12}{6} = 2 \text{ A}$$

$$V = E - ir = 12 - 2 \times 2$$

$$= 12 - 4 = 8 \text{ Volt.}$$

229. An electron moves in a circular orbit of radius 5.3×10^{-11} m with a speed of 2.2×10^{6} m-s^{-1}. What is the equivalent current in the orbit ?

Ans : **Main 2021**

Radius of circular orbit,

$$r = 5.3 \times 10^{-11} \text{ m}$$

and speed of electron,

$$v = 2.2 \times 10^{6} \text{ m-s}^{-1}$$

The time-taken by an electron to complete one round along the circular orbit,

$$t = \frac{\text{Circumference}}{\text{Speed}}$$

$$= \frac{2\pi r}{\upsilon}$$

The equivalent current in the orbit,

$$I = \frac{e}{t}$$

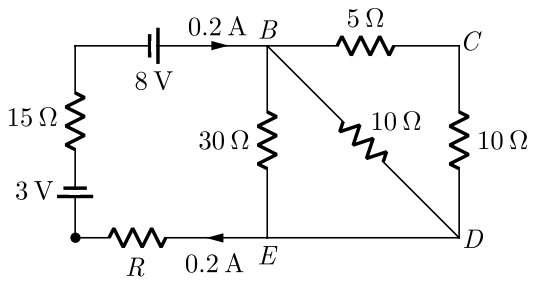
$$= \frac{e}{\frac{2\pi r}{v}} = \frac{e \times \upsilon}{2\pi r}$$

where, e = Charge on an electron equal to 1.6×10^{-19} C

$$= \frac{(1.6 \times 10^{-19}) \times (2.2 \times 10^{6})}{2 \times 3.14 \times (5.3 \times 10^{-11})}$$

$$= 1.1 \times 10^{-3} \text{ A}$$

230. Calculate the value of the resistance R in the circuit shown in the figure so that the current in the circuit is 0.2 A. What would be the potential difference between points B and E?



Ans : **Main 2013, 2010**

(i) The effective resistance between B and E as BC and CD are in series and BD, BCD and BED are in parallel.

So,
$$\frac{1}{R_{BE}} = \frac{1}{15} + \frac{1}{10} + \frac{1}{30}$$

$$= \frac{2+3+1}{30}$$

$$R_{BE} = 5\,\Omega$$

(ii) Using Kirchhoff's law in loop.

$$02 \times 5 + 0.2R + 15 \times 0.2 = 8 - 3$$

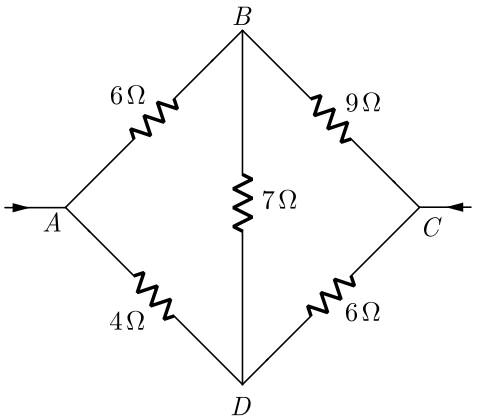
$$1 + 0.2R + 3 = 5$$

$$0.2R = 1$$

$$R = 5\,\Omega$$

(iii) $$V_{BE} = 5(0.2) = 1 \text{ Volt}$$

231. Find the equivalent resistance between the points A and C of the given network of resistors (see figure).



Ans : **Main 2000**

Clearly, the given circuit diagram is a condition of a balanced Wheatstone bridge $\left(\frac{R_1}{R_2} = \frac{R_3}{R_4}\right)$.

So, no current will flow through the branch BD (7 Ω resistor). The equivalent resistance of the branch ABC as they are in series = 6 + 9 = 15 Ω

The equivalent resistance of the branch ADC as they are in series = 4 + 6 = 10 Ω

Again, the combination forms parallel connection.

So, the total effective resistance of the circuit is

$$\frac{1}{R} = \frac{1}{15} + \frac{1}{10} = \frac{5}{30} = \frac{1}{6}$$

$$R = 6\,\Omega$$

232. The resistance of a galvanometer is 50 Ω. It is converted into

(i) a voltmeter using a 10 kΩ resistor.

(ii) an ammeter using a 10 mΩ resistor.

Calculate the resistance of the voltmeter and the ammeter to an accuracy of 2 significant figures only.

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239. Eight identical cells, each of emf 2 V and internal resistance $3\,\Omega$, are connected in series to form a row. Six such rows are connected in parallel to form a battery. This battery is now connected to an external resistor R of resistance $6\,\Omega$. Calculate.

(a) emf of the battery.

(b) internal resistance of the battery

(c) current flowing through R.

Ans : **Main 2023, 2017**

(a) The emf of each cell is 2 V, so the emf of battery consisting of six rows connected in parallel is

$$E_{battery} = 6 \times 2\,\text{V} = 12\,\text{V}$$

(b) The internal resistance of a single cell is $32\,\Omega$. When six rows of cells are connected in parallel the equivalent internal resistance of the battery is

$$\frac{1}{R_{\text{internal}}} = \frac{1}{32}+\frac{1}{32}+\frac{1}{32}+\frac{1}{32}+\frac{1}{32}+\frac{1}{32}$$

$$= \frac{6}{32}$$

$$R_{\text{internal}} = \frac{32}{6} = 5.33\,\Omega$$

(c) To calculate the current flowing through R, first we need to calculate the total resistance of the circuit;

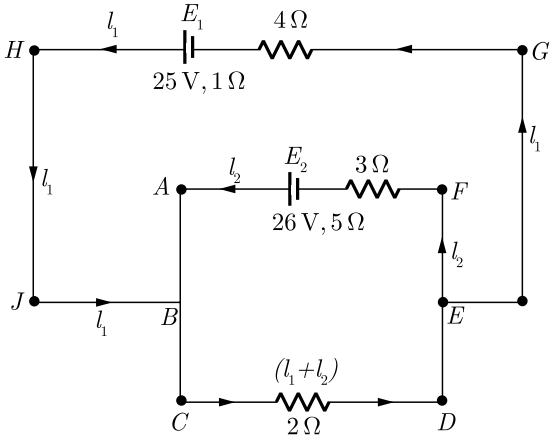
$$R_{\text{total}} = 62 + 5.33 = 67.33\,\Omega$$

Using Ohm's law, the current flowing through R is

$$I = \frac{\varepsilon}{R_{\text{total}}} = \frac{12\,\text{V}}{67.33\,\Omega} = 0.178\,\text{A}$$

Therefore, the current flowing through R is 0.178 A.

240. In the circuit shown in figure below, E_1 and E_2 are batteries having emfs of 25 V and 26 V. They have an internal resistance of $1\,\Omega$ and $5\,\Omega$, respectively. Applying Kirchhoff's laws of electrical networks, calculate the currents I_1 and I_2.



Ans : **Comp 2015**

Considering loop $ABCDEF$ in the same order and applying Kirchhoff's voltage law,

$$3I_2 + 2(I_1+I_2) - (25 - I_1) = 0$$

$$2I_1 + 10I_2 = 26 \quad ...(1)$$

Considering loop $HICDGH$ in the same order and applying Kirchhoff's voltage law,

$$4I_1 + 2(I_1+I_2) - (25 - I_1) = 0$$

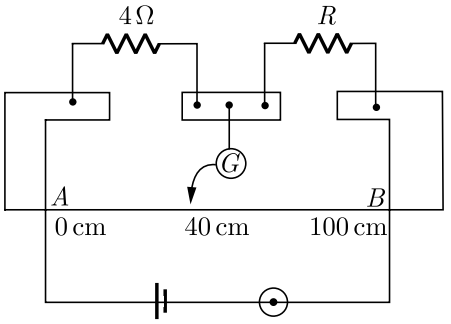
$$7I_1 + 2I_2 = 25 \quad ...(2)$$

Solving Eqs. (1) and (2), we get

$$I_1 = 3\,\text{A}$$

Putting this in Eq.(1), we get $I_2 = 2\,\text{A}$

241. In a meter bridge circuit, resistance in the left gap is $4\,\Omega$ and an unknown resistance R is in the right-hand gap as shown in figure below. The null point is found to be 40 cm from the left end of the wire.



(a) Calculate the value of the unknown resistance R.

(b) What change will you make in R to bring the null point to the midpoint of the wire AB ?

Ans : **SQP 2023**

(a) From formula

$$\frac{P}{Q} = \frac{R}{S}$$

$$\frac{40}{60} = \frac{4}{R}$$

$$R = 6\,\Omega$$

(b) If the null point to the midpoint of the wire AB, then $P = Q = 50$ cm

$$\frac{P}{Q} = \frac{R}{S}$$

$$\frac{50}{50} = \frac{6}{R}$$

$$R = 6\,\Omega$$

NODIA

Ans : **Main 2018**

In loop $BEFAB$,

$$-5(I_1+I_2)-7I_1-I_1+34-4I_1=0$$

$$17I_1+5I_2=34 \quad ...(1)$$

In loop BEDCB,

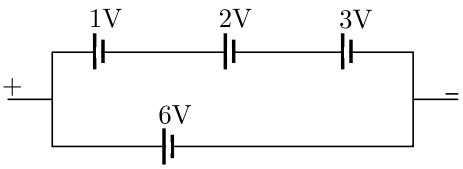
$$-5(I_1+I_2)-7I_2-2I_2+10-4I_2=0$$

$$18I_2+5I_1=10 \quad ...(2)$$

Solving Eqs. (1) and (2), we get

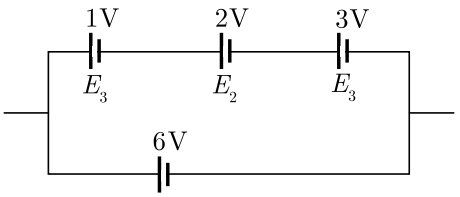
$$I_1=2\,\text{A} \text{ and } I_2=0$$

236. Find the emf of the battery shown in the figure.



Ans : **Main 2014, 2007**

Consider the circuit. Let the emf of the battery is E_{eq}. It is clear from the figure that the cells E_1, E_2 and E_3 are in series.

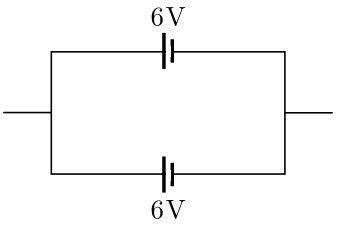


So, equivalent emf

$$E_4=E_1+E_2+E_3$$

$$=3\,\text{V}+2\,\text{V}+1\,\text{V}=6\,\text{V}$$

As the two cells are in parallel



So, equivalent emf E_{eq} = emf of single cell = 6 V

237. A 10 m long uniform metallic wire having a resistance of 20 Ω is used as potentiometer wire. This wire is connected in series with another resistance of 480 Ω and a battery of emf 5 V having negligible internal resistance. If an unknown emf e is balanced across 6 m of the potentiometer wire, calculate

(i) the potential gradient across the potentiometer wire.

(ii) the value of the unknown emf e.

Ans : **Main 2015**

$$l_1=10\,\text{m},\ R=20\,\Omega,$$

$$R_1=480\,\Omega,\ E_1=5\,\text{V},$$

balancing length $l_2=6\,\text{m}$

(i) The potential gradient across the potentiometer wire is given by

$$K=\frac{V}{l}=\frac{5}{6}=0.83\,\text{V/m}$$

(ii) We know that $\frac{E_1}{E_2}=\frac{l_1}{l_2}$

Substituting the all values,

$$\frac{5}{E_2}=\frac{10}{6}$$

$$E_2=\frac{6\times5}{10}=3\,\text{V}$$

238. Two wires A and B of equal masses and of the same material are taken. The diameter of wire A is half the diameter of wire B. If the resistance of wire A is 24 Ω, calculate the resistance of wire B.

Ans : **Main 2006**

Resistance $R=\rho\frac{l}{A}$

$$R_A=\frac{\rho l_A}{\pi r_A^2},\ R_B=\frac{\rho l_B}{\pi r_B^2}$$

Where, symbols having their usual meaning.

Same mass and same material. Let d be the density of both wires respectively. Then, according to the question

$$M_A=M_B$$

[where, M_A, M_B masses of A and B]

$$\pi r_A^2 l_A d=\pi r_B^2 l_B d$$

$$\frac{\pi r_B^2}{4} l_A d=\pi r_B^2 l_B d \qquad \left[r_A=\frac{r_B}{2}\right]$$

$$l_A=4l_B$$

[Where, l_A, l_B are the lengths of the two wires]

$$\frac{R_B}{R_A}=\frac{\rho l_B}{4\pi r_A^2}\cdot\frac{\pi r_A^2}{\rho l_A}$$

[Where, R_A, R_B are the resistances of the wires A and B and ρ is the resistivity]

$$\frac{R_B}{R_A}=\frac{l_B}{4l_A}=\frac{1}{16}$$

$$R_B=\frac{24}{16}=1.5\,\Omega$$

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$$R_1 = 60\,\Omega$$

Hence applying $P_1 = \dfrac{V^2}{R_1}$

$$V^2 = P_1 R_1 = 15 \times 60$$

$$V^2 = 900$$

$$V = \sqrt{900} = 30\text{ V}$$

Same V is applied for both R_1 and R_2,

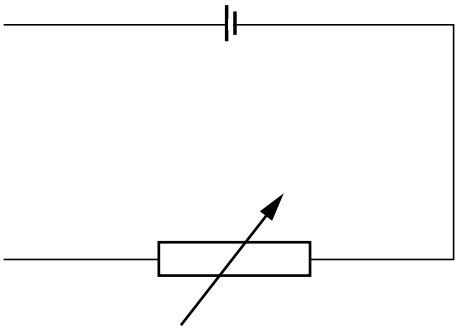
Total power, $P_{\text{Total}} = \dfrac{V^2}{R_{\text{eq}}} = \dfrac{(30)^2}{36}$

$$= \frac{30 \times 30}{36} = 25\text{ W}$$

Hence, P_2 (Power consumed by resistance R_2)

$$= P_{\text{Total}} - P_1 = 25 - 15 = 10\text{ W}$$

257. A circuit is used to determine the internal resistance and the emf of a cell. It consists of the cell, a variable resistor, an ideal ammeter A and an ideal voltmeter V. Figure shows part of the circuit with the ammeter and voltmeter missing.



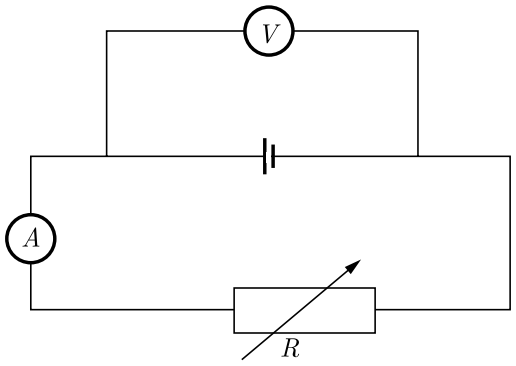
The variable resistor is set to be $1.5\,\Omega$. When the cell converts 7.2 mJ of energy, 5.8 mC of charge moves completely around the circuit. The potential difference across the variable resistor is 0.55 V.

(a) Redraw the diagram showing the positions of the ammeter and the voltmeter.

(b) Calculate the emf of the cell.

Ans : **SQP 2014**

(a)



(b) $P = VI$

$$E = VIt$$

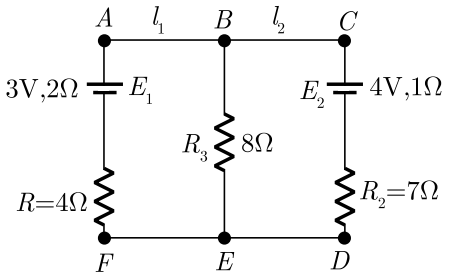
$$E = V\frac{q}{t}t$$

$$E = Vq$$

$$V = E/q$$

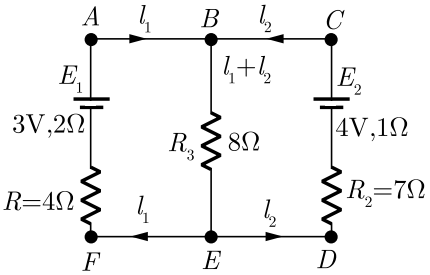
$$= \frac{7.2 \times 10^{-3}}{5.8 \times 10^{-3}} = 1.24\text{ V}$$

258. E_1 and E_2 are two batteries having emfs of 3 V and 4 V and internal resistances of $2\,\Omega$ and $1\,\Omega$, respectively. They are connected as shown in figure below. Using Kirchhoff's laws of electrical circuits, calculate the currents I_1 and I_2.



Ans : **Main 2020**

Considering the figure given in the question, when we consider the loop $ABEFA$ and apply Kirchhoff's second law to it, then



$$8(I_1 + I_2) + I_1 \times 4 + I_1 \times 2 = 3$$

$$8I_1 + 8I_2 + 4I_1 + 2I_1 = 3$$

$$14I_1 + 8I_2 = 3 \qquad \ldots(1)$$

If we consider the loop $BEDCB$ and apply Kirchhoff's second law,

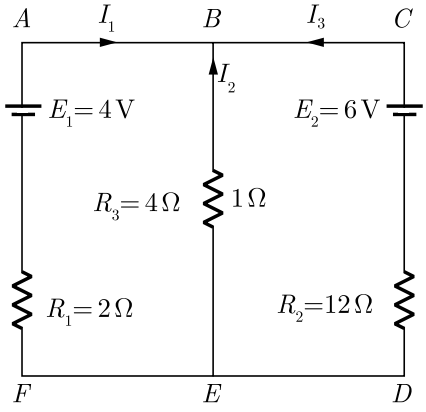
$$8(I_1 + I_2) + I_2 \times 7 + I_2 \times 1 = 4$$

$$8I_1 + 8I_2 + 7I_2 + I_2 = 4$$

$$8I_1 + 16I_2 = 4$$

$$2I_1 + 4I_2 = 1 \qquad \ldots(2)$$

242. In the circuit given alongside, E_1 and E_2 are two cells of emfs 4 V and 6 V respectively, having negligible internal resistances. Applying Kirchhoff's laws of electrical networks, find the values of I_1 and I_2.



Ans : **Main 2008, 2004**

Currents and emfs are shown in the given circuit. Now, applying Kirchhoff's second law in closed loop $ABEFA$,

$$4 = (I_1 + I_2)4 + I_1 \times 2$$

$$4 = 4I_1 + 4I_2 + 2I_1$$

$$4 = 6I_1 + 4I_2 \quad ...(1)$$

Similarly, in closed loop $BCDEB$,

$$6 = 4(I_1 + I_2) + 12I_2$$

$$6 = 4I_1 + 16I_2 \quad ...(2)$$

On solving Eqs. (1) and (2), we get

$$6I_1 + 4I_2 = 4 \text{ and } I_1 + 4I_2 = 3/2$$

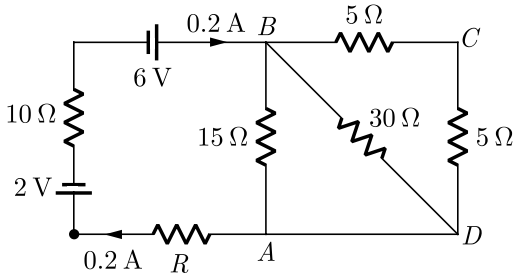
$$5I_1 = \frac{5}{2}$$

$$I_1 = 0.5 \text{ A}$$

Substituting $I_1 = 0.5$ A in Eq. (1), we get

$$I_2 = 0.25 \text{ A}$$

243. Calculate the value of the resistance R in the circuit shown in the figure so that the current in the circuit is 0.2 A. What would be the potential difference between points A and B ?



Ans : **Main 2010**

For BCD, equivalent resistance

$$R_1 = 5 + 5 = 10\,\Omega$$

Across BA, equivalent resistance R_2

$$\frac{1}{R_2} = \frac{1}{10} + \frac{1}{30} + \frac{1}{15}$$

$$= \frac{3+1+2}{30} = \frac{6}{30} = \frac{1}{5}$$

$$R_2 = 5\,\Omega$$

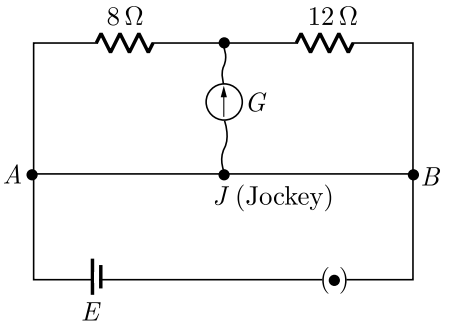
Potential difference

$$V_{BA} = I \times R_2 = 0.2 \times 5$$

$$V_{BA} = 1 \text{ Volt}$$

$$V_{AB} = -1 \text{ Volt}$$

244. In the circuit (given figure below) the length of the wire $AB = 400$ cm. Where should the jockey J be placed, so that the galvanometer shows a zero deflection?

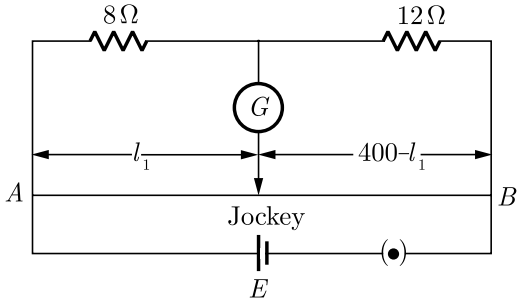


Ans : **Main 2006**

By Wheatstone's bridge principle,

Resistance $(R) \propto$ Length (l)

$$\frac{R_1}{R_2} = \frac{l_1}{l_2}$$



According to the figure,

$$\frac{8}{12} = \frac{l_1}{400 - l_1}$$

$$3200 - 8l_1 = 12l_1$$

$$l_1 = \frac{3200}{20} = 160 \text{ cm from end } A$$

NODIA

Ans : Main 2003

(i) Total resistance of voltmeter

$$= 50 + 10000 = 10050$$

$$= 1.01 \times 10^4\,\Omega$$

$$= 1.0 \times 10^4\,\Omega$$

$$10\,\text{M}\Omega = 10 \times 10^{-3}\,\Omega$$

(ii) Resistance of ammeter

$$= \frac{1}{R} = \frac{1}{50} + \frac{1}{10^{-2}}$$

$$= \frac{1}{50} + 100$$

$$= 0.02 + 100 = 100.02\,\Omega$$

$$R = \frac{1}{100.02} = 0.009998$$

$$= 9.99 \times 10^{-3}\,\Omega$$

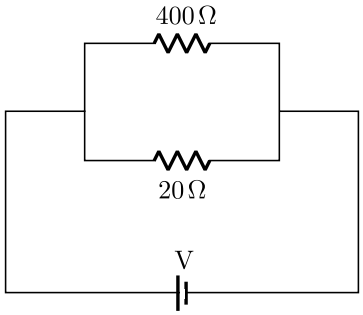
$$= 10 \times 10^{-3}\,\Omega$$

233. Two resistors $R_1 = 400\,\Omega$ and $R_2 = 20\,\Omega$ are connected in the parallel to a battery. If heating power developed in R_1 is 25 W, find the heating power developed in R_2

Ans : Main 2015, 2012

Given, $R_1 = 400\,\Omega,\ R_2 = 20\,\Omega,$

power across $P_1 = 25\ \text{W}$



We know that $P_1 = \frac{V^2}{R}$

$$V^2 = P_1 \times R_1$$

$$= 25 \times 400$$

$$V = \sqrt{10000} = 100\ \text{V}$$

For the both resistors, voltage is same due to the parallel combination of resistors.

Power across R_2,

$$P_2 = \frac{V^2}{R_2}$$

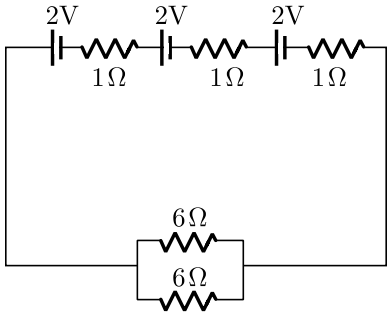
$$= \frac{(100)^2}{20} = \frac{100 \times 100}{20}$$

$$P_2 = 500\ \text{W}$$

234. Three identical cells each of emf 2 V and internal resistance $1\,\Omega$ are connected in series to form a battery. The battery is then connected to a parallel combination of two identical resistors, each of resistance $6\,\Omega$. Find the current delivered by the battery.

Ans : Main 2015

As shown in the figure , all $1\,\Omega$ resistors are in the series combination and $6\,\Omega$ resistors are in parallel combination. So, the equivalent resistance of the circuit,



$$R_T = 1 + 1 + 1 + \frac{6 \times 6}{6 + 6}$$

$$R_T = 3 + \frac{36}{12}$$

$$R_T = 6\,\Omega$$

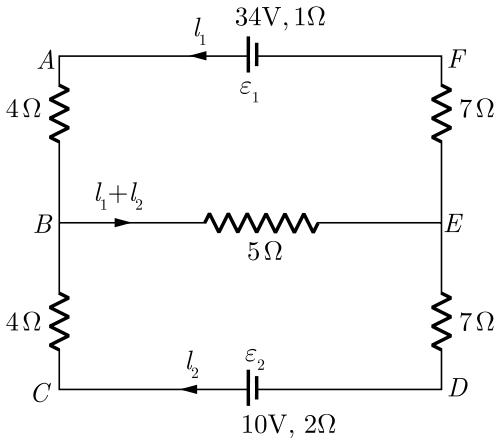
Total voltage of the circuit,

$$V_T = 2 + 2 + 2 = 6\ \text{V}$$

Now current in the circuit,

$$I = \frac{V_T}{R_T} = \frac{6}{6} = 1\ \text{A}$$

235. ε_1 and ε_2 are two batteries having emf of 34 V and 10 V respectively and internal resistance of $1\,\Omega$and $2\,\Omega$, respectively. They are connected as shown in figure below. Using Kirchhoff's laws of electrical networks, calculate the currents I_1 and I_2.



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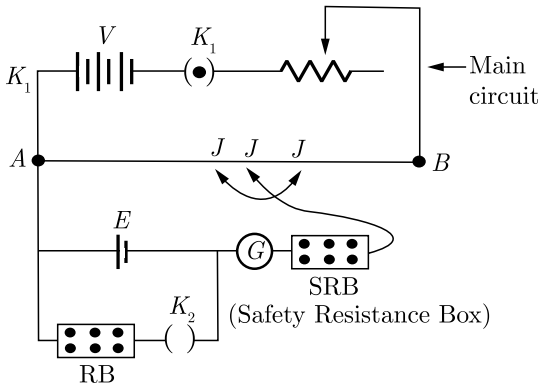
248. Draw a circuit diagram for the determination of the internal resistance of a cell using a potentiometer. Derive the formula to be used.

Ans : **Main 2002**

Consider the following diagram -



Let E is potential difference across l_1.

As $(E \propto l_1)$. So, $E = kl_1$ ...(1)

V is potential difference across l_2,

So, $V = Kl_2$ ...(2)

On dividing Eq. (1) by Eq. (2), we get

$$\frac{E}{V} = \frac{kl_1}{kl_2} \Rightarrow \frac{E}{V} = \frac{l_1}{l_2}$$

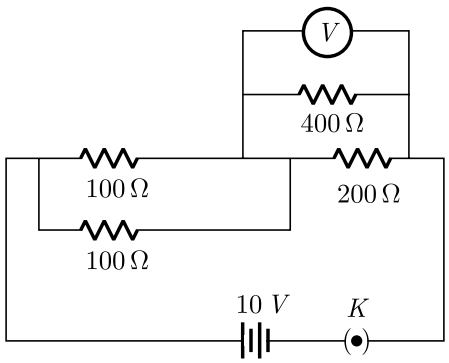
Let r be the internal resistance of the cell. If current I flows through the cell when it is shunted with resistance R from safety box then from ohm's law

$$E = I(R + r) \text{ and } V = IR$$

$$\frac{E}{V} = \frac{R + V}{R}$$

$$r = R\left(\frac{l_1}{l_2} - 1\right)$$

249. Given that the resistance of the voltmeter is $400\,\Omega$. Find the voltmeter's reading.



Ans : **Main 2004, 2001**

Let, R_V is the resistance of the voltmeter. This R_V is in parallel with $200\,\Omega$ resistance, The equivalent resistance of $200\,\Omega$ and $400\,\Omega$ is

$$\frac{1}{R'} = \frac{1}{400} + \frac{1}{200}$$

on $R' = 133.33\,\Omega$

Again from the figure two resistances of $100\,\Omega$ each are in parallel to each other. Their equivalent resistance is R'', then

$$\frac{1}{R''} = \frac{1}{100} + \frac{1}{100}$$

$$R'' = 50\,\Omega$$

Now, according to the questions, R' and R'' are in series, therefore their equivalent resistance R will be

$$R = 133.33 + 50 = 183.33\,\Omega$$

$$V = 10 \text{ Volt}$$

Total current through voltmeter

$$I = \frac{V}{R} = \frac{10}{183.33} = 0.054 \text{ A}$$

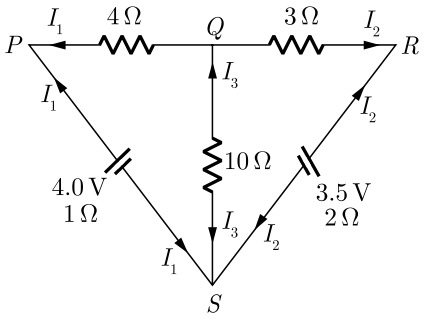
Voltmeter reading,

$$V = IR'$$

$$= 0.054 \times 133.33$$

$$= 7.19 \text{ Volt}$$

250. In the circuit shown in figure, E_1 and E_2 are batteries having emfs 4.0 V and 3.5 V respectively and internal resistances $1\,\Omega$ and $2\,\Omega$ respectively. Using Kirchhoff's laws, calculate currents I_1, I_2, and I_3.



Ans : **Main 2011, 2007**

We have to apply Kirchhoff's first law for current division and Kirchhoff's second law for potential differences in each loop. Applying Kirchhoff's second law for closed mesh $PQSP$,

$$1I_1 + 4I_1 + 10(I_1 + I_2) = 4$$

as $I_3 = I_1 + I_2$

[by applying Kirchhoff's I law at point Q]

$$15I_1 + 10I_2 = 4 \quad ...(1)$$

NODIA

245. An electric bulb is rated 100 W for 220 V A.C. supply of 50 Hz. Calculate

1. The resistance of the bulb.
2. The r.m.s. current through the bulb.

Ans : SQP 2020, 2011

Power, $P = 100\ \text{W}$

Voltage, $V = 220\ \text{Volt}$

Frequency, $\nu = 50\ \text{Hz}$

1.

$$P = I^2 R$$

Since, $I = \dfrac{V}{R}$

Hence, $P = \dfrac{V^2}{R}$

$$= \frac{220 \times 220}{100} = 484\ \Omega$$

2.

$$V_{\text{rms}} = \frac{V_0}{\sqrt{2}}$$

$$V_0 = V_{\text{rms}} \times \sqrt{2}$$

$$= 220\sqrt{2} = 311.12$$

Now, $I_{\text{rms}} = \dfrac{I_0}{\sqrt{2}} = \dfrac{V_0}{R\sqrt{2}}$

$$= \frac{311.12}{484 \times \sqrt{2}} = 0.45\ \text{A}$$

246. A uniform copper wire having mass of 2.4×10^{-3} kg carries a current of 1 A and has a potential difference of 1.8 V across its ends. If density and resistivity of copper are $9.6 \times 10^3\ \text{kg-m}^{-3}$ and $1.8 \times 10^{-8}\ \Omega$-m respectively, What is the length of copper wire?

Ans : Main 2016, 2007

Mass of wire, $m = 2.4 \times 10^{-3}\ \text{kg}$

Current in wire, $I = 1\ \text{A}$

Potential difference,

$$V = 1.8\ \text{Volt}$$

Density of copper, $d = 9.6 \times 10^3\ \text{kg-m}^{-3}$

and its resistivity, $\rho = 1.8 \times 10^{-8}\ \Omega\text{–m}$

We know that volume of wire,

$$Al = \frac{m}{d}$$

$$= \frac{2.4 \times 10^{-3}}{9.6 \times 10^3}$$

$$= 0.25 \times 10^{-6} \quad \ldots(1)$$

The resistance of the wire is given by

$$R = \rho \times \frac{l}{A} = \frac{V}{I}$$

$$\frac{l}{A} = \frac{V}{I\rho}$$

where, l = Length of wire

$$= \frac{1.8}{1 \times (1.8 \times 10^{-8})}$$

$$= 10^8 \quad \ldots(2)$$

Multiplying equation (1) and (2),we get

$$l^2 = 0.25 \times 10^2$$

$$= 25$$

$$l = 5\ \text{m}$$

247. Two resistances $2\,\Omega$ and $8\,\Omega$ are connected in parallel. Similarly, two other resistances of $6\,\Omega$ and $9\,\Omega$ are connected in parallel. If both the combination are connected in series, what is the effective resistance of the system?

Ans : SQP 2012

First resistance, $R_1 = 2\,\Omega$

Second resistance, $R_2 = 8\,\Omega$

Third resistance, $R_3 = 6\,\Omega$

Fourth resistance, $R_4 = 9\,\Omega$

We know that effective resistance of parallel combination of $2\,\Omega$ and $8\,\Omega$ resistances,

$$R = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$= \frac{2 \times 8}{2 + 8}$$

$$= \frac{16}{10} = 1.6\,\Omega$$

Similarly, effective resistance of parallel combination of $6\,\Omega$ and $9\,\Omega$ resistances,

$$R' = \frac{R_3 \times R_4}{R_3 + R_4}$$

$$= \frac{6 \times 9}{6 + 9}$$

$$= \frac{54}{15} = 3.6\,\Omega$$

Now effective resistance of the resistances R and R' are in series combination,

$$R_{eff} = R + R'$$

$$= 1.6 + 3.6$$

$$= 5.2\,\Omega$$

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$$I = \frac{4}{3}\,\text{A}$$

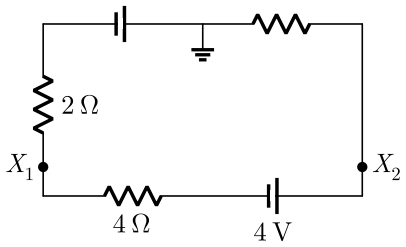
so, total current through R,

$$I = 1 + \frac{4}{3} = \frac{7}{3}\,\text{A}$$

Hence, Voltage drop across R;

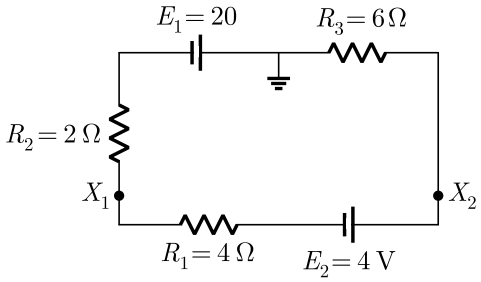
$$V = IR = \frac{7}{3}R \text{ Volt.}$$

254. Determine the potentials at the points X_1 and X_2 in the circuit.



Ans : SQP 2014

The circuit diagram given in the question is,



Effective emf. of the given circuit,

$$E_{eff} = E_1 - E_2$$
$$= 20 - 4 = 16 \text{ Volt}$$

Electric current in the circuit is given by,

$$I = \frac{E}{R_{eq}}$$

In the circuit R_1, R_2 and R_3 are connected in series combination,

Hence, $R_{eq} = R_1 + R_2 + R_3$

$$= 6 + 2 + 4 = 12\,\Omega$$

Now, $I = \frac{16}{12} = \frac{4}{3}A$

Using the KVL,

Potential at, $X_2 = R_3 \times I = 6 \times \frac{4}{3} = 8 \text{ Volt}$

Potential at, $X_1 = -R_2 I - (-20)$

$$= -2 \times \frac{4}{3} + 20$$

$$= \frac{52}{3} = 17.3 \text{ Volt}$$

255. A current flows in a wire of resistance $5\,\Omega$ having potential difference 7 volt for 20 minutes. How much heat produced in the wire?

Ans : SQP 2020

Given, resistance of wire,

$$R = 5\,\Omega$$

Potential difference across the wire,

$$V = 7 \text{ volts}$$

Time, $t = 20 \text{ min} = 20 \times 60 \text{ sec}$

Heat produced in wire,

$$H = I^2 Rt$$

Since, $V = IR$

Hence, $I = \frac{V}{R}$

$$= \left(\frac{V}{R}\right)^2 Rt = \frac{V^2}{R} \times t$$

$$= \frac{(7)^2 \times 20 \times 60}{5}$$

$$= \frac{7 \times 7 \times 20 \times 60}{5}$$

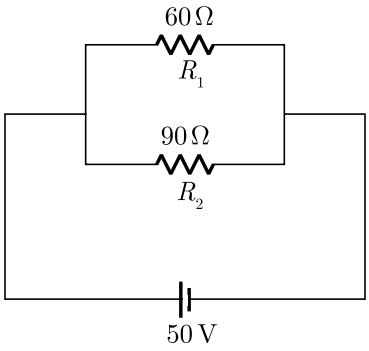
$$= \frac{58800}{5} = 11760\,\text{J}$$

$$= \frac{11760}{4.2}\,\text{Cal} \quad (1\text{Cal} = 4.2\,\text{J})$$

$$= 2800\,\text{Cal}$$

256. Two resistors $R_1 = 60\,\Omega$ and $R_2 = 90\,\Omega$ are connected in parallel. If electric power consumed by the resistor R_1 is 15 W, calculate the power consumed by the resistor R_2.

Ans : Main 2017



Equivalent resistance of the circuit $= R_{eq}$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$= \frac{1}{60} + \frac{1}{90} = \frac{3+2}{180} = \frac{5}{180}$$

$$R_{eq} = 36\,\Omega$$

Now, given $P_1 = 15\,\text{W}$

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Similarly, for closed loop $RQSR$,

$$2I_2 + 3I_2 + 10(I_1 + I_2) = 3.5$$
$$10I_1 + 15I_2 = 3.5 \quad ...(2)$$

On solving Eqs. (1) and (2), we get

$$I_1 = 0.2\,\text{A} \text{ and } I_2 = 0.1\,\text{A}$$
$$I_3 = I_1 + I_2 = 0.3\,\text{A}$$

Currents I_1, I_2 and I_3 are shown in the circuit diagram.

251. A 6V battery is connected to the terminals of a 3 m long wire of uniform thickness and of resistance 100 Ω. What is the potential difference between two points on the wire, separated by a distance of 50 cm?

Ans : **Comp 2013**

Voltage of battery, $V = 6$ Volt

Length of wire, $L = 3\,\text{m}$

Resistance of wire, $R = 100\,\Omega$

Length of small part of wire,

$$l = 50\,\text{cm} = 0.5\,\text{m}$$

We know that resistance of small part of wire,

$$R' = R \times \frac{l}{L}$$
$$= 100 \times \frac{0.5}{3} = \frac{50}{3}\,\Omega$$

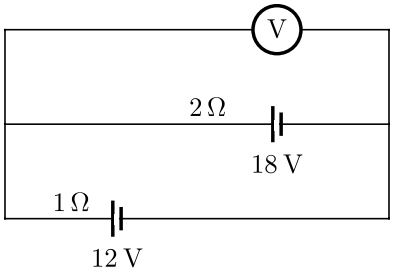
and current flowing through the wire,

$$I = \frac{V}{R} = \frac{6}{100} = \frac{3}{50}\,\text{A}$$

Therefore, potential difference between two points on the wire,

$$V' = IR'$$
$$= \frac{3}{50} \times \frac{50}{3} = 1\,\text{Volt}$$

252. Two batteries, one of e.m.f. 18 V and internal resistance 2 Ω and other of e.m.f. 12 volt and internal resistance 1 Ω are connected as shown in figure. What is the reading of voltmeter?



Ans : **Main 2013**

E.m.f. of first battery, $E_1 = 18$ Volt

Internal resistance of first battery, $r_1 = 2\,\Omega$

E.m.f. of second battery, $E_2 = 12$ Volt

Internal resistance of second battery, $r_2 = 1\,\Omega$

Reading of voltmeter $= V$

We know from the Kirchhoff's second law that in the circuit,

$$Ir_1 - E_1 + Ir_2 + E_2 = 0$$
$$(I \times 2) - 18 + (I \times 1) + 12 = 0$$
$$3I = 6$$
$$I = 2\,\text{A}$$

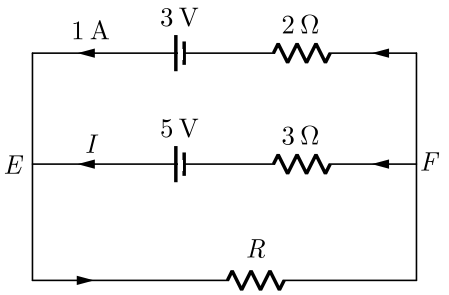
Therefore, voltage drop across r_1,

$$V_1 = Ir_1$$
$$= 2 \times 2 = 4\,\text{Volt}$$

Thus reading of voltmeter, $V = E_1 - V_1$

$$= 18 - 4 = 14\,\text{Volt}$$

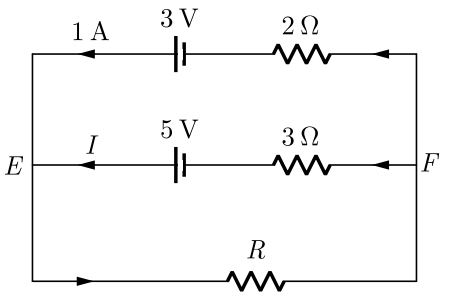
253. Using Kirchhoff's rule in the given circuit, determine (i) the voltage drop across the unknown resistor R and (ii) the current I in the arm EF.



Ans : **Main 2014, 2007**

Taking upper portion as mesh using Kirchhoff's second law

$$\Sigma IR = \Sigma E$$



$$1 \times 2 - I \times 3 = 3 - 5$$
$$2 - 3I = -2$$
$$3I = 4$$

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Equating Eqs. (1) and (2), we get

$$28I_1 + 16I_2 = 6 \quad ...(3)$$

$$28I_1 + 56I_2 = 14 \quad ...(4)$$

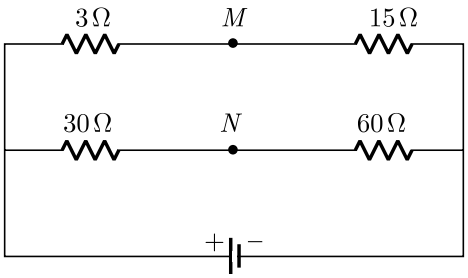
After solving Eqs. (3) and (4), we get

$$40I_2 = 8$$

$$I_2 = \frac{1}{5}\text{ A}$$

and $$I_1 = \frac{1}{10}\text{ A}\,[\text{from Eq.(1)}$$

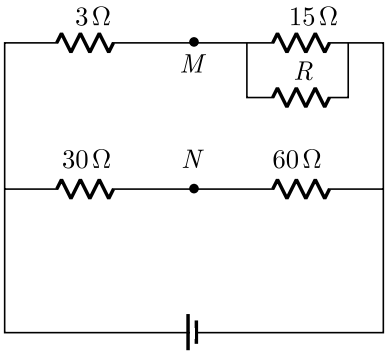
259. How much resistance should be connected to $15\,\Omega$ resistor shown in the circuit in figure below, so that the points M and N are at the same potential?



Ans : **Main 2013**

Current in the branch containing M is more, so resistance should be reduced and hence the connected resistance must be in parallel.

Let the resistance R is connected in parallel with resistance of $15\,\Omega$.



So, equivalent resistance

$$\frac{1}{R'} = \frac{1}{R} + \frac{1}{15}$$

$$= \frac{1}{R'} = \frac{R+15}{15R}$$

$$R' = \frac{15R}{R+15}$$

On applying Wheatstone bridge principle,

$$\frac{3}{30} = \frac{R'}{60}$$

$$= \frac{1}{10} = \frac{15R}{(R+15)60}$$

$$6(R+15) = 15R$$

$$6R + 90 = 15R$$

$$9R = 90$$

$$R = 10\,\Omega$$

Hence, $10\,\Omega$ resistance connected in parallel to $15\,\Omega$ resistance to have M and N with same potential.

260. The figure alongside shows a uniform manganin wire XY of length 100 cm and resistance $9\,\Omega$, connected to an accumulator D of emf 4 V and internal resistance $1\,\Omega$ through a variable resistance R. E is a cell of emf 1.8 V connected to the wire XY via jockey J and a galvanometer G. It is found that the galvanometer shows no deflection when $XJ = 80$ cm. Find the value of R.

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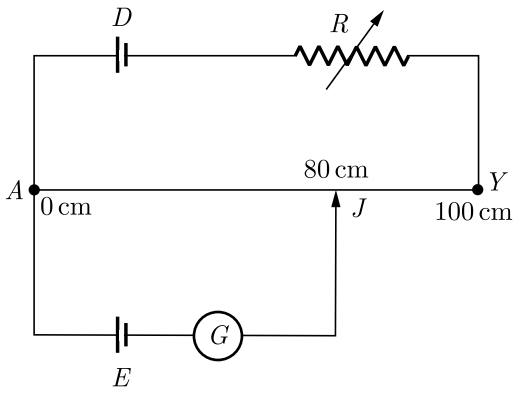


Ans : **Main 2009**

For no deflection in the galvanometer balanced condition should be achieved that a null point is obtained by the jockey (J).

The cell E is balanced at $l = 80$ cm

Let k is potential gradient.

$$E = kl$$

$$1.8 = k \times 0.80$$

$$k = 2.25\ \text{Vm}^{-1}$$

Potential gradient along the wire XY,

$$k = \frac{V}{l}$$

$[l =$ length of the wire $= 100$ cm $= 1$ m$]$

$$2.25 = \frac{V}{1}$$

$$V = 2.25\ \text{Volt}$$

Current in the potentiometer wire XY is

$$I = \frac{4}{1+R+9}$$

Now, $V = I \times$ Resistance of wire

278. Why is a potentiometer preferred over a voltmeter by determining the emf of a cell? Two cells of emf E_1 and E_2 are connected together in two ways shown below :

The balance points in a given potentiometer experiment to these two combinations of cells are found to be at 351.0 cm and 70.2 cm respectively. Calculate the ratio of the emfs of the two cells.

Ans : **SQP 2011, 2019**

A potentiometer does not draw any current from the cell whose emf is to be determined, whereas a voltmeter always drawn some current. Therefore, emf measured by voltmeter is slightly less than actual value of emf of the cell.

From the given data,

For $\dashv\vdash$ type of combination of cells (E_1 E_2)

$$E_1 + E_2 = K \cdot I_1 \quad ...(1)$$

and for $\dashv\vdash$ type of combination of cells (E_1 E_2)

$$E_1 + E_2 = K \cdot I_2 \quad ...(2)$$

Here, $I_1 = 351$ cm, $I_2 = 70.2$ cm

$$\frac{E_1 + E_2}{E_1 - E_2} = \frac{I_1}{I_2}$$

$$\frac{E_1 + E_2}{E_1 - E_2} = \frac{351}{70.2}$$

$$\frac{E_1 + E_2}{E_1 - E_2} = 5$$

$$E_1 + E_2 = 5E_1 - 5E_2$$

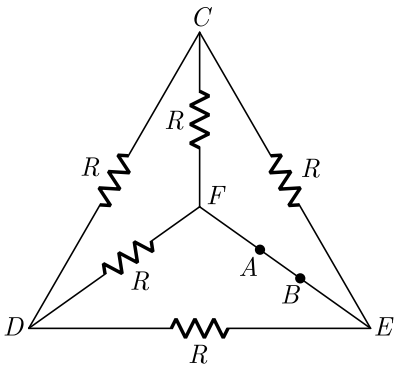
$$4E_1 = 6E_2$$

$$\frac{E_1}{E_2} = \frac{3}{2}$$

279. (i) Calculate the equivalent resistance of the given electrical network between points A and B.

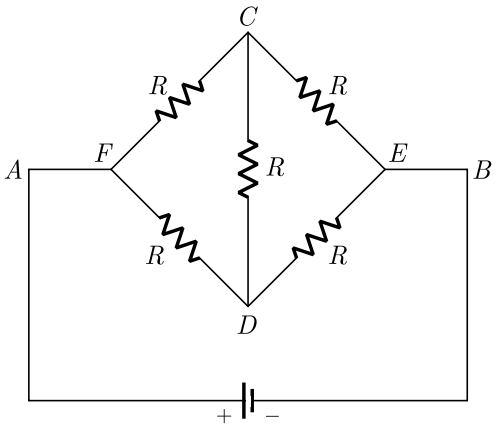
(ii) Also find the current through CD and ACE, if a 10 V DC source is connected between A and B and the value of R is assumed as $2\,\Omega$

Delhi 2014



Ans : **Main 2017, 2011**

(i) The simplified diagram of the given circuit in the question as follows :



The network is a balanced Wheatstone's bridge and hence, resistance of branch CD is neglected.

Hence,

Resistance of branch $RCE = R + R = 2R$

Resistance of branch $FDE = R + R = 2R$.

Hence, Equivalent resistance between A and B

$$R_{eq} = \frac{2R \times 2R}{2R + 2R} = R$$

(ii) If $R = 2\Omega$ then $R_{eq} = 2\,\Omega$

Hence, No current flows through CD in balanced condition of bridge.

Current in arm,

$$AFCEB = \frac{V}{2R} = \frac{10}{2 \times 2}$$

$$= 2.5 \text{ A}.$$

280. The network $PQRS$ shown in the circuit diagram, has the batteries of 4 V and 5 V and negligible internal resistance. A milliammeter of $20\,\Omega$ resistance is connected between P and R. Calculate the reading in the milliammeter.

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$$I_1 = \frac{5}{10} = 0.5\ \text{A}$$

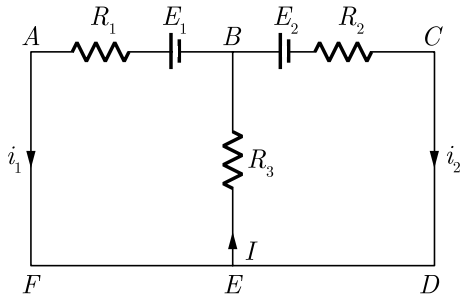
On substituting the value of I_1 in Eq. (1), we get

$$I_2 = 0.25\ \text{A}$$

$$I_1 = 0.5\ \text{A}$$

$$I_2 = 0.25\ \text{A}$$

263. In the circuit shown in figure, $E_1 = 17\ \text{V}$, $E_2 = 21\ \text{V}$, $R_1 = 2\,\Omega$, $R_2 = 3\,\Omega$ and $R_3 = 5\,\Omega$. Using Kirchhoff's laws, find the currents flowing through the resistors R_1, R_2 and R_3.
(Internal resistance of each of the batteries is negligible.)



Ans : **Main 2013, 2011**

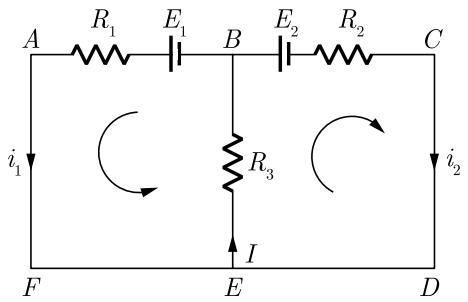
Apply Kirchhoff's current and voltage rule for each loop.

According to the figure

$$E_1 = 17\ \text{V},\ E_2 = 21\ \text{V}$$

$$R_1 = 2\,\Omega,\ R_2 = 3\,\Omega$$

and $$R_3 = 5\,\Omega$$



In loop $AFEBA$

$$E_1 - i_1R_1 - iR_3 = 0$$

$$17 = 2i_1 + 5i \quad \ldots(1)$$

In loop $BCDEB$

$$E_2 - i_2R_2 - iR_3 = 0$$

$$E_2 = i_2R_2 + iR_3$$

$$21 = 3i_2 = 5i \quad \ldots(2)$$

By Kirchhoff's I law

$$i_1 + i_2 = i \quad \ldots(3)$$

From Eqs. (1) and (2), we get

$$17 = 2i_1 + 5(i_1 + i_2)$$

$$= 2i_1 + 5i_1 + 5i_2$$

$$17 = 7i_1 + 5i_2 \quad \ldots(4)$$

From Eqs. (2) and (3), we get

$$21 = 3i_2 + 5(i_1 + i_2)$$

$$= 3i_2 + 5i_1 + 5i_2$$

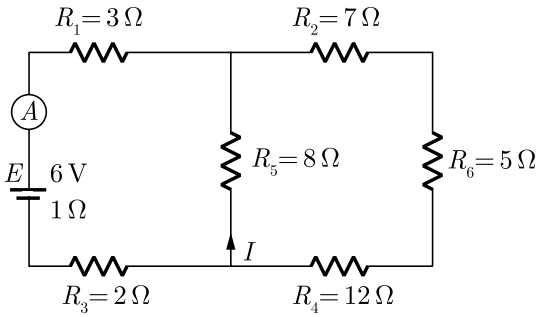
$$21 = 5i_1 + 8i_2 \quad \ldots(5)$$

On Solving Eqs. (4) and (5), we get

$$i_1 = 1\ \text{A},\ i_2 = 2\ \text{A}$$

$$i = i_1 + i_2 = 1 + 2 = 3\ \text{A}$$

264. In the circuit shown in figure given alongside, E is a battery of emf 6 V and internal resistance $1\,\Omega$. Find the reading of the ammeter A, if it has negligible resistance.



Ans : **Main 2012**

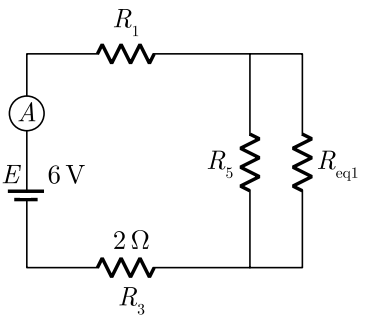
We have to find equivalent resistance in the circuit and then current can be calculated using $V = IR$.
According to the given circuit diagram,

$$R_{eq1} = R_2 + R_6 + R_4$$

[since R_2, R_6 and R_4 are in series]

$$= 7 + 5 + 12 = 24\,\Omega$$

Now, R_{eq1}, and R_5 are in parallel, so



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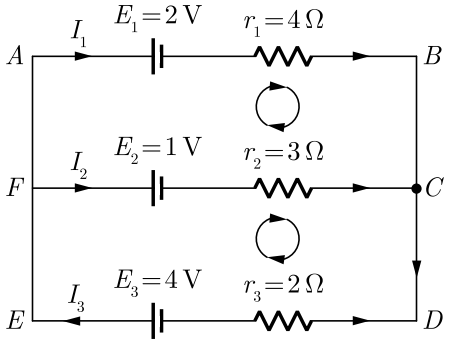
Ans : Comp 2015, 2003

For given circuit,



At F, applying junction rule,

$$I_3 = I_1 + I_2 \qquad ...(1)$$

In mesh $ABCFA$,

$$+2 + 4I_1 - 3I_2 - 1 = 0$$

$$4I_1 - 3I_2 = 1 \qquad ...(2)$$

In mesh $FCDEF$,

$$+1 + 3I_2 + 2I_3 - 4 = 0$$

$$3I_2 + 2I_3 = 3 \qquad ...(3)$$

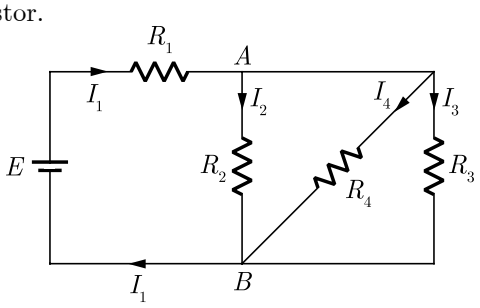
On solving Eq. (1), (2), (3), we get

$$I_1 = \frac{2}{13}\,A$$

$$I_2 = \frac{7}{13}\,A$$

$$I_3 = \frac{9}{13}\,A$$

270. In the circuit shown, $R_1 = 4\,\Omega$, $R_2 = R_3 = 5\,\Omega$, $R_4 = 10\,\Omega$ and $E = 6$ V. Work out the equivalent resistance of the circuit and the current in each resistor.



Ans : SQP 2019

Here, R_2, R_3 and R_4 are connected in parallel.

Their effective resistance R_p will be given by,

$$\frac{1}{R_p} = \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$$

$$\frac{1}{R_p} = \frac{1}{5} + \frac{1}{5} + \frac{1}{10}$$

or $$\frac{1}{R_p} = \frac{2+2+1}{10} = \frac{5}{10} = \frac{1}{2}$$

$$R_p = 2\,\Omega$$

Total resistance of circuit,

$$R = R_1 + R_p = 4 + 2 = 6\,\Omega$$

Current, $$I = \frac{6}{6} = 1\,A$$

Potential drop across,

$$R_1 = I_1 R_1 = 1 \times 4 = 4\,\text{Volt}$$

Potential drop across all other resistances,

$$= 6 - 4 = 2\,\text{Volt}$$

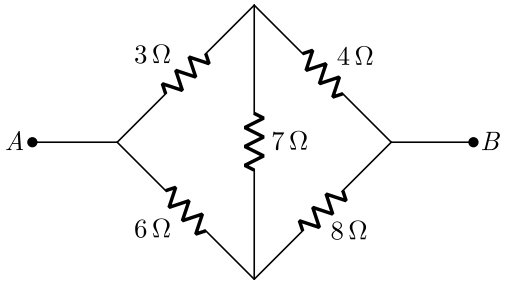
Current through R_2 and R_3,

$$I_2 = I_3 = \frac{2}{5}\,A$$

Current through R_4,

$$I_4 = \frac{2}{10} = \frac{1}{5}\,A$$

271. What is the equivalent resistance between A and B in the given figure?



Ans : Main 2011

Resistances, $R_1 = 3\,\Omega$, $R_2 = 4\,\Omega$, $R_3 = 6\,\Omega$

and $R_4 = 8\,\Omega$, $R_5 = 7\,\Omega$

We know that in the given circuit,

$$\frac{R_1}{R_3} = \frac{R_2}{R_4} = \frac{1}{2}$$

Thus it is a case of balanced Wheatstone bridge, in which $7\,\Omega$ resistance is ineffective.

Now resistances in the upper arms are in series combination. Therefore, their equivalent resistance,

$$R_V = R_1 + R_2 = 3 + 4 = 7\,\Omega$$

Similarly, equivalent resistance of the lower arms,

$$R_L = R_3 + R_4 = 6 + 8 = 14\,\Omega$$

Now equivalent resistances R_V and R_L are in parallel combination.

Therefore equivalent resistance between A and B

$$R_{AB} = \frac{R_U \times R_L}{R_U + R_L}$$

$$= \frac{7 \times 14}{7 + 14} = \frac{14}{3}\,\Omega$$

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267. Use Kirchhoff's laws to determine the value of current I_1 in the given electrical circuit.

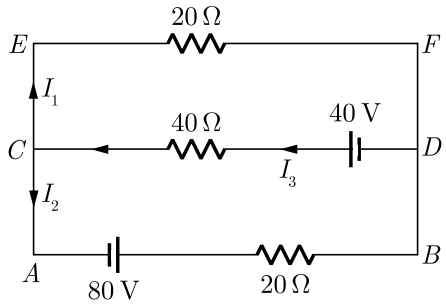
Ans : **Main 2020**

From Kirchhoff's first law at junction C,

$$I_3 = I_1 + I_2 \quad ...(1)$$

Applying Kirchhoff's second law in mesh $CDFEC$

$$40I_3 - 40 + 20I_1 = 0$$
$$20(2I_3 + I_1) = 40$$
$$I_1 + 2I_3 = 2 \quad ...(2)$$



Applying Kirchhoff's second law to mesh $ABFEA$

$$80 - 20I_2 + 20I_1 = 0$$
$$20(I_1 - I_2) = -80$$
$$I_2 - I_1 = 4 \quad ...(3)$$

Substituting value of I_3 from eq. (1) in eq. (2), we get

$$I_1 + 2(I_1 + I_2) = 2$$
$$3I_1 + 2I_2 = 2 \quad ...(4)$$

Multiplying equation (3) by 2, we get

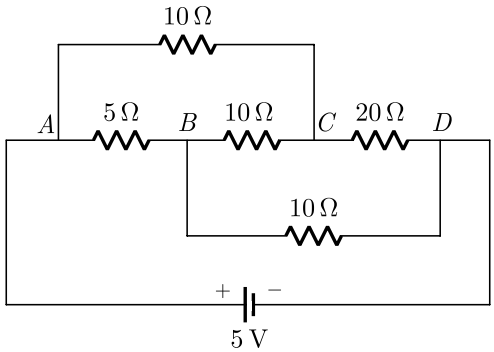
$$2I_2 - 2I_1 = 8 \quad ...(5)$$

Subtracting eq. (4) from eq. (5), we get

$$5I_1 = -6$$
$$I_1 = -\frac{6}{5}\text{ A} = -1.2\text{ A}$$

Here negative sign shows that current is in opposite direction.

268. Calculate the value of the current drawn from a 5 V battery in the circuit as shown:



Ans : **Main 2013**

The equivalent wheatstone bridge for the given combination is shown in figure.

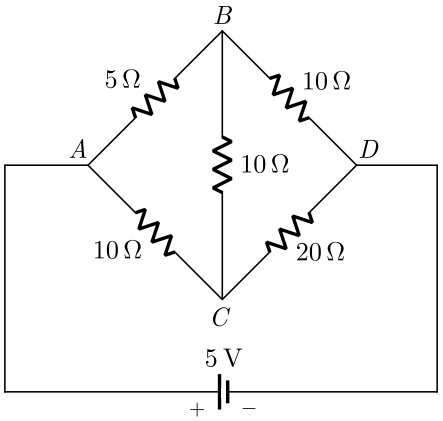
The resistance of arm ACD,

$$R_{S_1} = 10 + 20 = 30\,\Omega$$

Also, the resistance of arm ABD,

$$R_{S_2} = 5 + 10 = 15\,\Omega$$

Since, the condition $\frac{P}{Q} = \frac{R}{S}$ is satisfied, it is a balanced bridge.



No current flows along arm BC.

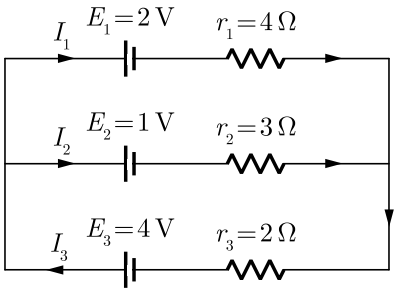
Equivalent resistance,

$$R_{eq.} = \frac{R_{S_1} \times R_{S_2}}{R_{S_1} + R_{S_2}} = \frac{30 \times 15}{30 + 15}$$
$$= \frac{30 \times 15}{45} = 10\,\Omega$$

Current draw from the source,

$$I = \frac{V}{R_{eq.}}$$
$$= \frac{5}{10} = \frac{1}{2}\text{ A} = 0.5\text{ A}$$

269. Using Kirchhoff's Law, write the expression for the currents I_1, I_2 and I_3 in the circuit diagram shown.



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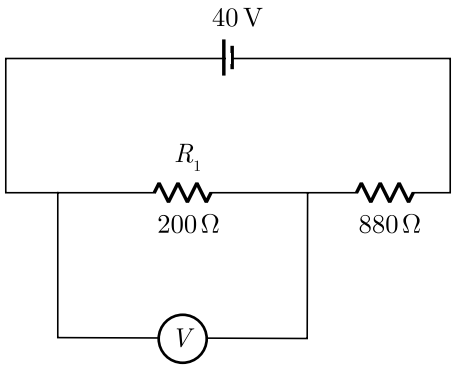
$$2.25 = \frac{4}{1+R+9} \times 9$$

$$2.25 = \frac{36}{10+R}$$

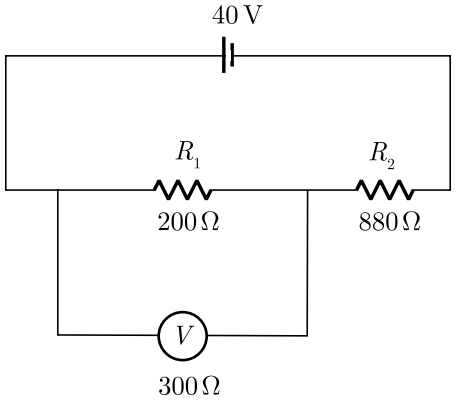
$$10+R = \frac{36}{2.25} = 16$$

$$R = 16-10 = 6\,\Omega$$

261. Figure below shows two resistors R_1 and R_2 connected to a battery having an emf of 40 V and negligible internal resistance. A voltmeter having a resistance of 300 Ω is used to measure potential difference across R_1. Find the reading of the voltmeter.



Ans : **Main 2017**



According to Ohm's law,we get

$$V = IR$$

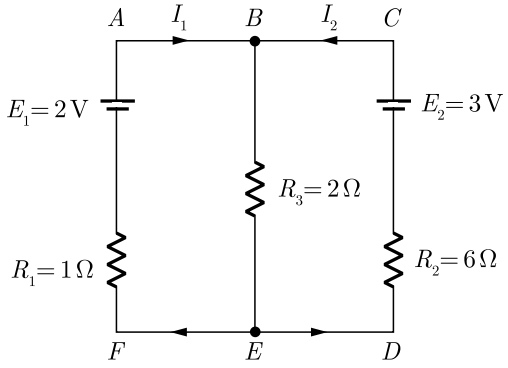
$$I = \frac{V}{R} = \frac{40}{1080} \qquad \begin{bmatrix} R_s = R_1 + R_2 \\ = 200 + 880 \\ = 1080\,\Omega \end{bmatrix}$$

$$= \frac{1}{27}\,\text{A}$$

Now, for R_1, potential difference $V = IR_1$

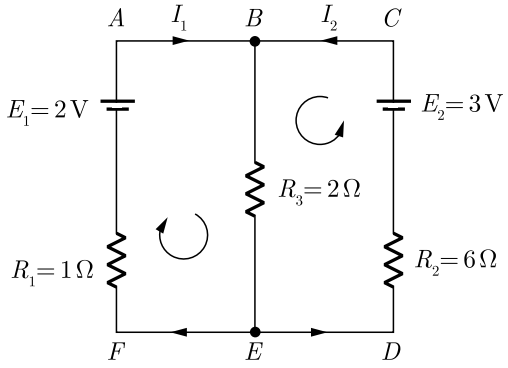
$$= \frac{1}{27} \times 200 = 7.40\,\text{V}$$

262. In the circuit shown in figure below, E_1 and E_2 are cells having emfs 2 V and 3 V respectively and negligible internal resistances. Applying Kirchhoff's laws of electrical networks find the values of currents I_1 and I_2.



Ans : **Main 2016**

Consider the figure given in the question,



Consider the loop *ABEFA* and apply Kirchhoff's second law to it.

$$2(I_1+I_2)+I_1 \times 1 = 2$$

$$2I_1+2I_2+I_1 = 2$$

$$3I_1+2I_2 = 2 \qquad ...(1)$$

Consider the loop *BCDEB* and apply Kirchhoff's second law to it.

$$2(I_1+I_2)+6I_2 = 3$$

$$2I_1+2I_2+6I_2 = 3$$

$$2I_1+8I_2 = 3 \qquad ...(2)$$

On multiplying Eq. (1) by 4, we get

$$12I_1+8I_2 = 8 \qquad ...(3)$$

On solving Eqs. (2) and (3), we get

$$12I_1+8I_2 = 8$$

$$2I_1+8I_2 = 3$$

$$- \quad - \quad -$$

$$10I_1 = 5$$

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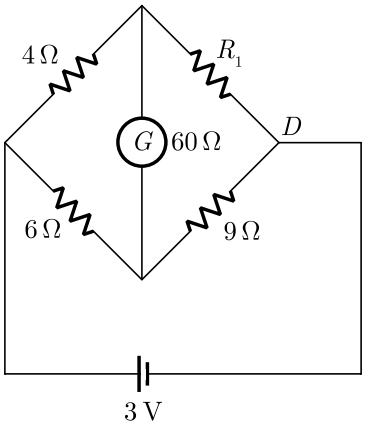
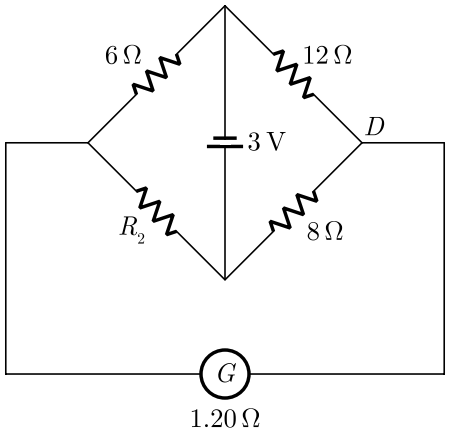
272. Figure shows two circuits each having a galvanometer and a battery of 3 V. When the galvanometers in each arrangement do not show any deflection, obtain the ratio $\frac{R_1}{R_2}$.





Ans : SQP 2009

For balanced Wheatstone bridge, if no current flows through the galvanometer.

$$\frac{4}{R_1} = \frac{6}{9}$$

$$R_1 = \frac{4 \times 9}{6}$$

$$= 6\,\Omega$$

For another current,

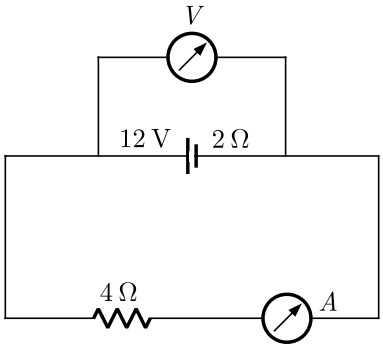
$$\frac{6}{12} = \frac{R_2}{8}$$

$$R_2 = \frac{6 \times 8}{12}$$

$$= 4\Omega$$

Hence, $$\frac{R_1}{R_2} = \frac{6}{4} = \frac{3}{2}$$

273. A battery of emf 12 V and internal resistance 2 Ω is connected to a 4 Ω resistor as shown in the figure.



(i) Show that a voltmeter when placed across the cell and across the resistor in turn gives the same reading.

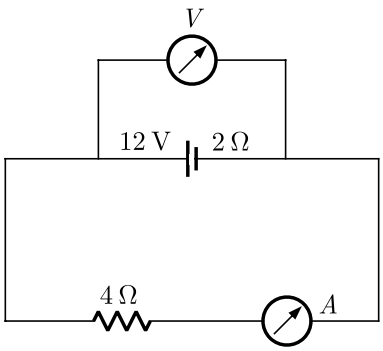
(ii) To record the voltage and the current in the circuit why is voltmeter placed in parallel and ammeter in series in the circuit?

Ans : Main 2016, 2012

(i) **Case I :** When voltmeter is placed across the cell effective resistance of the circuit.

$$R_{eq} = (2+4)\,\Omega = 6\,\Omega$$

$$I = \frac{12}{6}\,\text{A} = 2\,\text{A}$$



Terminal potential differences across the cell

$$V = E - Ir$$

$$V = 12 - 2(2) = 8 \text{ Volt}$$

Case II : When voltmeter is placed parallel across the resistor

Voltage across resistance

= current through resistance × resistance

$= 2 \times 4 = 8$ Volt

Hence, the voltmeter gives the same reading in the two cases.

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$$\frac{1}{R_{eq_2}} = \frac{1}{R_5} + \frac{1}{R_{eq1}}$$
$$= \frac{1}{8} + \frac{1}{24} = \frac{3+1}{24}$$
$$= \frac{4}{24} = \frac{1}{6}$$
$$R_{eq2} = 6\,\Omega$$

Now, R_{in}, R_{eq2}, R_1 and R_3 are in series, so

$$R_{eq} = R_{eq2} + R_1 + R_3 + R_{in}$$
$$= 6 + 3 + 2 + 1 = 12\,\Omega$$

The current measured by ammeter

$$I = \frac{V}{R}$$
$$= \frac{6}{12} = \frac{1}{2} = 0.5\text{ A}$$

265. When two resistors are connected in series and parallel, then their equivalent resistances are $16\,\Omega$ and $3\,\Omega$ respectively. Find out the resistance of each resistor.

Ans : Comp 2019, 2015

Equivalent resistance in series,

$$R_s = 16\,\Omega$$

Equivalent resistance in parallel,

$$R_p = 3\,\Omega$$

Let two resistors are R_1 and R_2 respectively. According to the question, when resistor are connected in series combination than.

Equivalent resistance,

$$R_s = R_1 + R_2$$
$$16 = R_1 + R_2$$
$$R_1 + R_2 = 16 \quad ...(1)$$

Similarly in parallel combination,

$$R_p = \frac{R_1 \times R_2}{R_1 + R_2}$$

From equation (1), $3 = \frac{R_1 R_2}{16}$

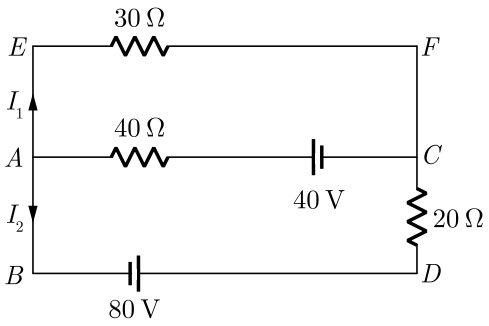
$$R_1 R_2 = 48$$
$$R_2 = \frac{48}{R_1} \quad ...(2)$$

Substitute the value of R_2 in equation (1), we get

$$R_1 + \frac{48}{R_1} = 16$$
$$R_1^2 + 48 = 16\,R_1$$
$$R_1^2 - 16R_1 + 48 = 0$$
$$R_1^2 - 12R_1 - 4R_1 + 48 = 0$$
$$R_1(R_1 - 12) - 4(R_1 - 12) = 0$$
$$(R_1 - 4)(R_1 - 12) = 0$$
$$R_1 = 4 \text{ or } 12\,\Omega$$

From equation (1), $R_2 = 12 \text{ or } 4\,\Omega$

266.



(a) Using Kirchhoff's rules, calculate the current in the arm AC of the given circuit.

(b) On what principle does the meter bridge work? Why are the metal strips used in the bridge?

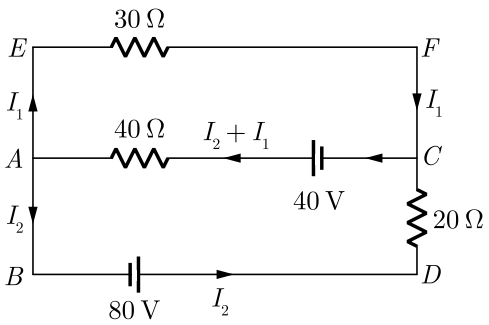
Ans : Main 2013, 2017

(a) For the mesh $EFCAE$,

$$-30I_1 + 40 - 40(I_1 + I_2) = 0$$
$$-7I_1 - 4I_2 = 4$$
$$7I_1 + 4I_2 = 4 \quad ...(1)$$

For the mesh $ACDBA$,

$$40(I_1 + I_2) - 40 + 20I_2 - 80 = 0$$
$$40I_1 + 60I_2 - 120 = 0$$
$$2I_2 + 3I_2 = 6 \quad ...(2)$$



Solving eqs. (1) and (2), we get

$$I_1 = \frac{-12}{13} A$$
$$I_2 = \frac{34}{13} A$$

Current through arm,

$$AC = I_1 + I_2 = \frac{22}{13} A$$

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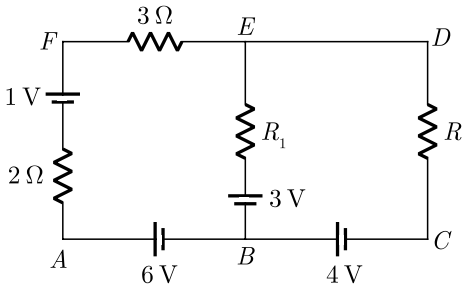
By applying Kirchhoff's loop law, we get

$$1.5 + 1.5 + R(1.5)\ 9 - 3$$

$$R = 2\,\Omega$$

Potential difference between A and D $= 9 - 3 =$ 6 Volt.

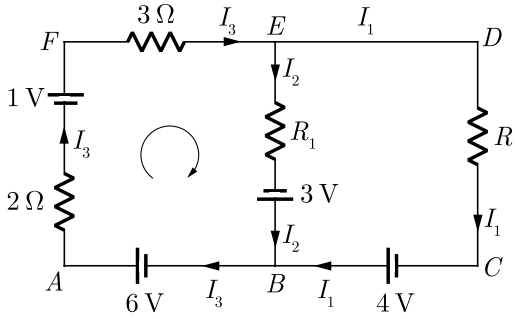
276. Use Kirchhoff's rules to determine the potential difference between the points A and D when no current flows in the arm BE of the electric network shown in the figure.



Ans : **Main 2015**

According to Kirchhoff's junction rule at E or B

$$I_3 = I_2 + I_1$$



Since, $I_2 = 0$ in the arm BE as given in the question.

$$I_3 = I_1$$

Using loop rule in loop $AFEBA$

$$+6\,V - 2I_3 + 1\,V - 3I_3 - I_2R_1 + 3\,V = 0$$

$$2I_3 + 3I_3 + I_2R_1 = 10 \text{ Volt}$$

Since, $I_2 = 0$,

so $5I_3 = 10$ Volt

$$I_3 = 2 \text{ A}$$

The potential difference between A and D, along the branch $AFCD$ of the closed circuit

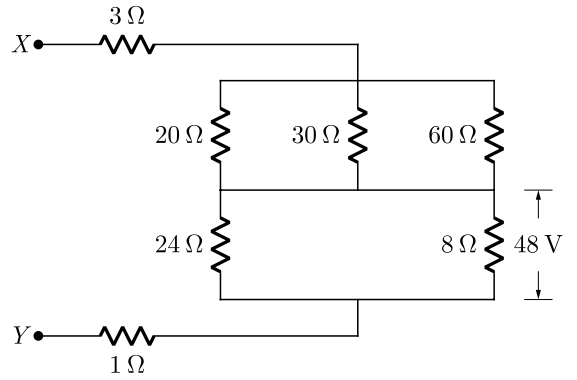
$$V_A - 2I_3 + 1\,V - 3I_3 - V_D = 0$$

$$V_A - V_D = 2I_3 - 1 + I_3$$

$$= 2 \times 2 - 1 + 3 \times 2$$

$$= 9 \text{ Volt}$$

277. The potential difference across $8\,\Omega$ resistance is 48 V as shown in the figure. What is the value of potential difference across X and Y terminal ?



Ans : **SQP 2008**

Potential difference across $8\,\Omega$ resistor,

$$V = 48 \text{ Volt}$$

We know that resistances $24\,\Omega$ and $8\,\Omega$ are in parallel combination Therefore their equivalent resistance,

$$R' = \frac{24 \times 8}{24 + 8}$$

$$= 6\,\Omega$$

Similarly, the resistances $20\,\Omega$, $30\,\Omega$ and $60\,\Omega$ are in parallel combination Therefore relation for their equivalent resistance is,

$$\frac{1}{R''} = \frac{1}{20} + \frac{1}{30} + \frac{1}{60} = \frac{1}{10}$$

or, $$R'' = 10\,\Omega$$

Now the resistances $3\,\Omega$, R'', R' and $1\,\Omega$ are connected in series combination.

Therefore effective resistance between X and Y,

$$R_{XY} = 3 + R' + R'' + 1$$

$$= 3 + 6 + 10 + 1$$

$$= 20\,\Omega$$

We also know that current in the circuit,

$$I = \frac{V}{R'}$$

$$= \frac{48}{6} = 8 \text{ A}$$

Therefore potential difference across X and Y,

$$V_{XY} = I \times R_{XY}$$

$$= 8 \times 20$$

$$= 160 \text{ Volt}$$

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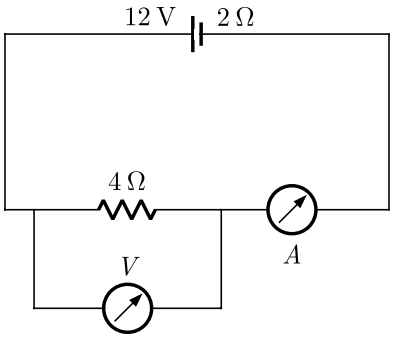


(ii) In series, current in the circuit remains same. In parallel, potential in the circuit remains same.

274. Two identical cells of emf 1.5 V each joined in parallel supply energy to an external circuit consisting of two resistances of 7 Ω each joined in parallel. A very high resistance voltmeter reads the terminal voltage of cells to be 1.4 V. Calculate the internal resistance of each cell.

Ans : **Main 2016**

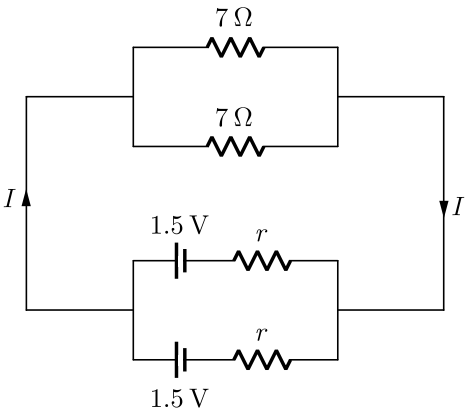
Given, $E = 1.5$ Volt,

$V = 1.4$ Volt.

Resistance of external circuit = Equivalent resistance of two resistances of 7 Ω connected in parallel

or $$R = \frac{R_1 R_2}{R_1 + R_2}$$

$$= \frac{7 \times 7}{7 + 7} = 3.5\,\Omega$$



Let r' be the total internal resistance of the two cells, then

$$r' = \left(\frac{E - V}{V}\right) R$$

$$= \left(\frac{1.5 - 1.4}{1.4}\right) 3.5 = 0.25\,\Omega$$

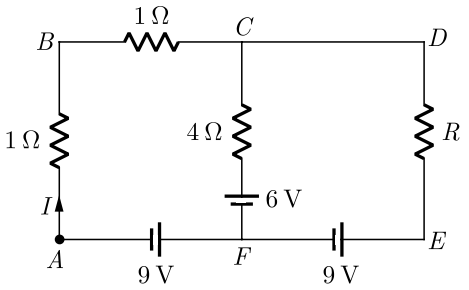
As the two cells of internal resistance r each have been connected in parallel, so

$$\frac{1}{r'} = \frac{1}{r} + \frac{1}{r}$$

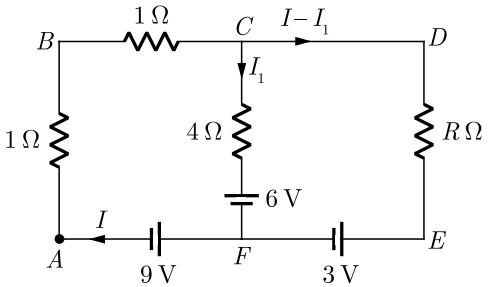
$$\frac{1}{0.25} = \frac{2}{r}$$

$$r = 0.25 \times 2 = 0.5\,\Omega$$

275. Using Kirchhoff's rules determine the value of unknown resistance R in the circuit so that no current flows through 4 Ω resistance. Also find the potential difference between A and D.



Ans : **SQP 2008, 2005**



Apply Kirchhoff's law in loop $ABCFA$:

$$I + I + 4I_1 = 9 - 6$$

$$2I + 4I_1 = 3 \qquad ...(1)$$

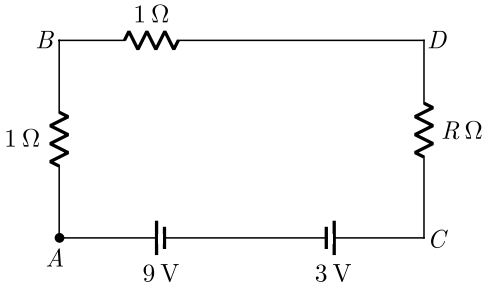
As there is no current flowing through the 4 Ω resistance,

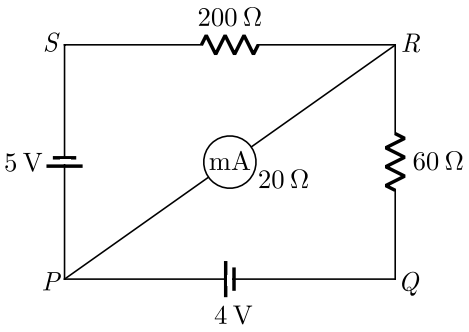
$$I_1 = 0$$

$$2I = 3$$

$$I = 1.5 \text{ A}$$

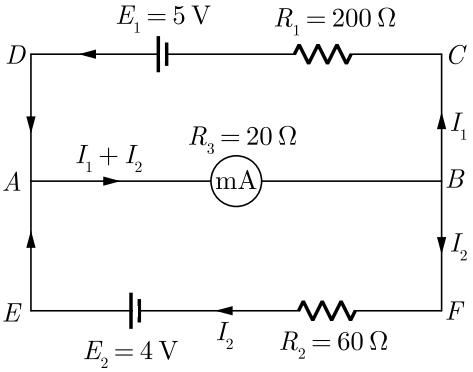
Thus, the current through resistance R is 1.5 A. As there is no current through branch CF, thus equivalent circuit will be





Ans : SQP 2017, 2012

Let us redraw circuit as shown



Using Kirchhoff's voltage law in closed loop $DABCD$

$$(I_1 + I_2)\,R_3 + I_1 R_1 - E_1 = 0 \quad ...(1)$$

In closed a loop $ABFEA$

$$(I_1 + I_2)\,R_3 + I_2 R_2 - E_2 = 0 \quad ...(2)$$

Multiplying eg. (1) by $(R_2 + R_3)$ and eq. (2) by R_3 and subtracting, we get

$$I_1 = \frac{E_1R_2 + E_1R_3 - E_2R_3}{R_1R_2 + R_2R_3 + R_1R_3}$$

$$= \frac{5 \times 60 + 5 \times 20 - 4 \times 20}{200 \times 60 + 60 \times 20 + 200 \times 20}$$

$$= \frac{300 + 100 - 80}{12000 + 1200 + 4000}$$

$$= \frac{320}{17200}\,\text{A}$$

Similarly, $I_2 = \dfrac{E_2R_1 + E_2R_3 - E_1R_3}{R_1R_2 + R_2R_3 + R_1R_3}$

$$= \frac{4 \times 200 + 4 \times 20 - 5 \times 20}{200 \times 60 + 60 \times 20 + 200 \times 20}$$

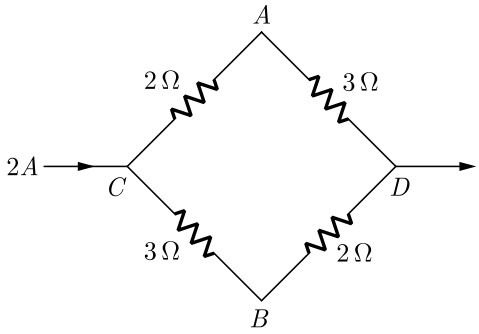
$$= \frac{800 + 80 - 100}{17200} = \frac{780}{1700}\,\text{A}$$

Hence, total current in mA $= I_1 + I_2$

$$= \frac{320}{17200} + \frac{780}{17200} = \frac{1100}{17200}$$

$$= \frac{11}{172}\,\text{A} = 64\ \text{mA}$$

281. A current of 2 A flows in a system as shown in the figure. What is the potential difference between A and B $(V_A - V_B)$?



Ans : SQP 2010

Resistances, $R_1 = 2\,\Omega$

$R_2 = 3\,\Omega$

$R_3 = 3\,\Omega$

and $R_4 = 2\,\Omega$

We know that resistances $2\,\Omega$ and $3\,\Omega$ (in the upper) arm are in series combination.

Therefore their equivalent resistance,

$$R_U = 2 + 3 = 5\,\Omega$$

Similarly, equivalent resistance of the lower arm,

$$R_L = 3 + 2 = 5\,\Omega$$

Since the equivalent resistance of both arms are equal, therefore current flowing through the upper and lower arms will also be equal,

i.e., $I_1 = I_2 = \dfrac{2}{2} = 1\,\text{A}$

We also know that potential difference between C and A,

$$V_C - V_A = I_1R_1$$

$$= 1 \times 2$$

$$= 2\ \text{Volt} \quad ...(1)$$

Similarly, potential difference between C and B,

$$V_C - V_B = I_2R_2$$

$$= 1 \times 3$$

$$= 3\ \text{Volt} \quad ...(2)$$

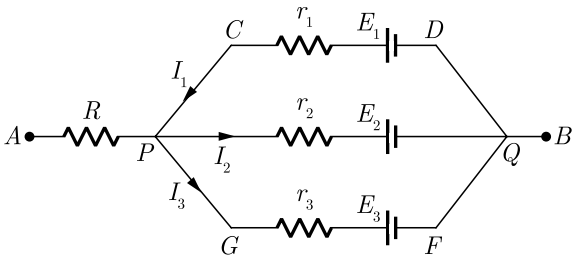
Subtracting equation (1) from (2),

$$V_C - V_B - (V_C - V_A) = 3 - 2$$

$$V_A - V_B = 1\ \text{Volt}$$

282. In the circuit shown below, cell E_1 has e.m.f. of 3 V, cell E_2 has e.m.f. of 2 V, cell E_3 has e.m.f. of 1 V and $R = r_1 = r_2 = r_3 = 1\,\Omega$. What is the potential difference between points A and B ?

NODIA



Ans : SQP 2016

E.m.f. of first cell, $E_1 = 3\,\text{Volt}$

E.m.f. of second cell, $E_2 = 2\,\text{Volt}$

E.m.f. of third cell, $E_3 = 1\,\text{Volt}$

And resistances, $R = r_1 = r_2 = r_3 = 1\,\Omega$

We know from the Kirchhoff's first law that at junction P,

$$I_1 = I_2 + I_3 \quad ..(1)$$

We also know from the Kirchhoff's second law that in the closed circuit $PQDCP$,

$$I_2 r_2 + E_2 - E_1 + I_1 r_1 = 0$$
$$(I_2 \times 1) + 2 - 3 + (I_1 \times 1) = 0$$
$$I_1 + I_2 = 1$$
$$(I_2 + I_3) + I_2 = 1$$
$$2I_2 + I_3 = 1 \quad ...(2)$$

Similarly, in the closed circuit $PQFGP$,

$$I_2 r_2 + E_2 - E_3 - I_3 r_3 = 0$$
$$(I_2 \times 1) + 2 - 1 - (I_3 \times 1) = 0$$
$$I_2 - I_3 = -1 \quad ...(3)$$

Now, adding equations (2) and (3),

$$3I_2 = 0$$
$$I_2 = 0$$

Again from equation (3),

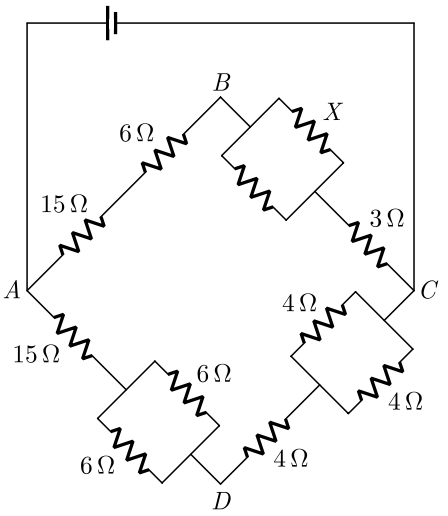
$$0 - I_3 = -1$$
$$I_3 = 1\,\text{A}$$

and from equation (1), $I_1 = 0 + 1 = 1\,\text{A}$

Since, no current flows through r_2 and R, therefore potential difference between A and B is equal to the potential difference between P and Q (i.e., e.m.f. of cell E_2).Thus potential difference between A and B,

$$V_{AB} = E_2 = 2\,\text{Volt}$$

283. In the given circuit, when the resistance between points B and D is zero. What is the value of the resistance X?



Ans : SQP 2014, 2012

Resistance between B and D,

$$R_{BD} = 0$$

We know that resistances between A and B are in series combination. Therefore, their equivalent resistance,

$$R_{AB} = 15 + 6 = 21\,\Omega$$

Now, the resistances between A and D are $15\,\Omega$ in series with $6\,\Omega$ and $6\,\Omega$ in parallel combination. Therefore, their equivalent resistance,

$$R_{AD} = 15 + \frac{6 \times 6}{6 + 6}$$
$$= 15 + \frac{36}{12} = 18\,\Omega$$

Similarly, equivalent resistance between D and C

$$R_{DC} = 4 + \frac{4 \times 4}{4 + 4}$$
$$= 4 + \frac{16}{8} = 6\,\Omega$$

and equivalent resistance between B and C,

$$R_{BC} = 3 + \frac{X \times 8}{X + 8}$$
$$= \frac{11X + 24}{X + 8}\,\Omega$$

We also know that as the resistance between BD is zero. Therefore, it is a balanced Wheatstone Bridge,

Hence, $$\frac{R_{AB}}{R_{AD}} = \frac{R_{BC}}{R_{DC}}$$

$$\frac{21}{18} = \frac{\frac{11X+24}{X+8}}{6}$$

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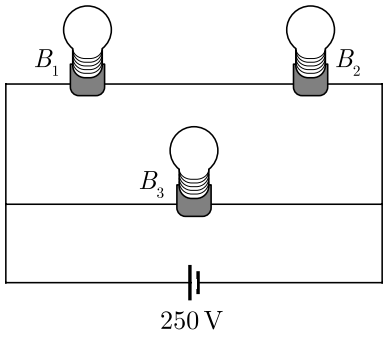
$$7X + 56 = 11X + 24$$
$$4X = 32$$
$$X = 8\,\Omega$$

284. A 100 W bulb B_1 and two 60 W bulbs B_2 and B_3, are connected to a 250 V source as shown in the figure. Now W_1, W_2 and W_3 are the output powers of the bulbs B_1, B_2 and B_3 respectively.

What is the relation between the output powers of bulbs?



Ans : **Comp 2006, 2003**

Power of bulb B_1, $P_1 = 100$ W

Power of bulb B_2, $P_2 = 60$ W

Power of bulb B_3, $P_3 = 60$ W

Source voltage, $V = 250$ Volt

Output power of bulb, $B_1 = W_1$

Output power of bulb, $B_2 = W_2$

Output power of bulb, $B_3 = W_3$

We know that resistance of bulb B_1,

$$R_1 = \frac{V^2}{P_1} = \frac{(250)^2}{100} = 625\,\Omega$$

Similarly, resistance of bulb B_2,

$$R_2 = \frac{V^2}{P_2} = \frac{(250)^2}{60} = 1042\,\Omega$$

and resistance of bulb B_3,

$$R_3 = \frac{V^2}{P_3} = \frac{(250)^2}{60} = 1042\,\Omega$$

We also know that as the resistance R_1 and R_2 are connected in series. Therefore, output power of bulb B_1,

$$W_1 = \frac{V^2}{(R_1 + R_2)} \times R_1$$
$$= \frac{(250)^2}{(625 + 1042)^2} \times 625$$
$$= 14.1\text{ W}$$

Similarly, output power of bulb B_2,

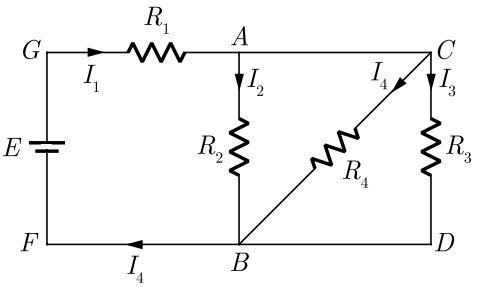
$$W_2 = \frac{V^2}{(R_1 + R_2)^2} \times R_2$$
$$= \frac{(250)^2}{(625 + 1042)^2} \times 1042$$
$$= 23.4\text{ W}$$

and output power of bulb B_3,

$$W_3 = \frac{V^2}{R_3^2} \times R_3$$
$$= \frac{(250)^2}{(1042)^2} \times 1042 = 60\text{ W}$$

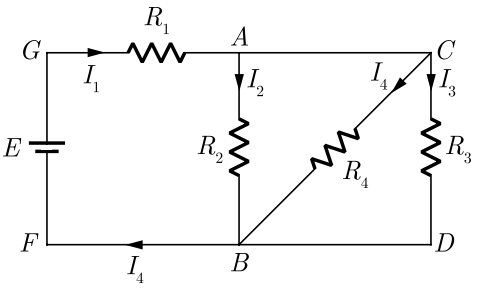
Therefore, $W_1 < W_2 < W_3$

285. In the circuit shown, $R_1 = 4\,\Omega$, $R_2 = R_3 = 15\,\Omega$, $R_4 = 30\,\Omega$ and $E = 10$ V. Calculate the equivalent resistance of the circuit and the current in each resistor.



Ans : **SQP 2017**

Given network is as follows :



(i) As R_3 and R_4 are in parallel, so

$$\frac{1}{R_{34}} = \frac{1}{30} + \frac{1}{15} = \frac{1+2}{30} = \frac{3}{30}\,\Omega$$

or $$R_{34} = 10\,\Omega$$

Now R_2 and R_{34} are in parallel, so

$$\frac{1}{R_{234}} = \frac{1}{15} + \frac{1}{10} = \frac{2+3}{30} = \frac{5}{30}$$
$$R_{234} = 6\,\Omega$$

Finally, R_1 and R_{234} are in series, so

$$R_{eq} = R_1 + R_{234} = 4 + 6 = 10\,\Omega$$

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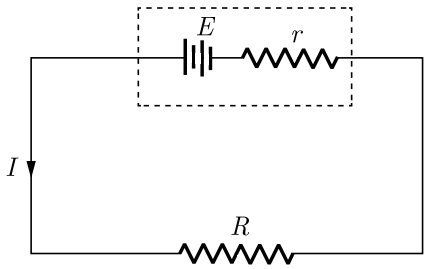
heat energy lost per unit area per unit time (h) (neglecting heat loses from ends of the wire).

$$P = I^2R = h \times 2\pi rl \qquad \left[R = \frac{\rho I}{\pi r^2}\right]$$

Where r and I are the length and radius of fuse wire, respectively.

A battery is described by its e.m.f. (E) and internal resistance (r). Efficiency of a battery (η) is defined as the ratio of the output power to the input power.

$$\eta = \frac{\text{Output power}}{\text{Input power}} \times 100\%$$



But, $I = \dfrac{E}{R+r}$, input power $= EI$

Output power $= EI - I^2r$

Then, $\eta = \left(\dfrac{EI - I^2r}{EI}\right) \times 100 \left(1 - \dfrac{Ir}{E}\right) \times 100$

$$= 1 - \left(\frac{E}{R+r}\right)\left(\frac{r}{E}\right) \times 100$$

$$\eta = \left(\frac{R}{R+r}\right) \times 100$$

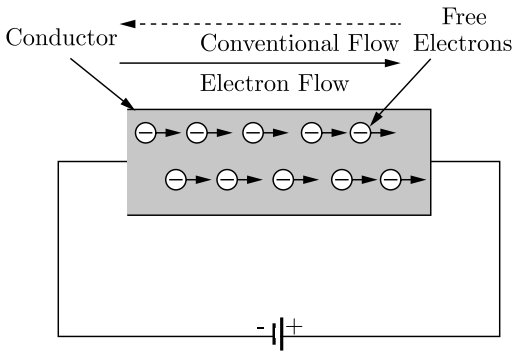
We know that output power of a source is maximum when the external resistance is equal to internal resistance, i.e., $R = r$.

1. Two fuse wires of same potential material are having length ratio 1 : 2 and ratio 4 : 1. What is the ratio of their current rating ?
2. Efficiency of a battery when delivering maximum power is

Ans :

1. 8 : 1
2. 40%

294. Electron move more easily through some conductors than others when potential difference is applied. The opposition of a conductor to current is called its resistance. Collisions are the basic cause of opposition. When potential difference is applied across the ends of a conductor,its free electrons get accelerated. On their way, they frequently collide with positive metal ions, i.e., their motion is opposed and this opposition to the flow of electron is called resistance. The number of collisions that the electrons make with atoms/ ions depends on the arrangement of atoms or ions in the conductor. A long wire offers more resistance than short wire because there will be more collisions. A thick wire offers less resistance than a thin wire because in a thick wire more area of cross section is available for the flow of electrons. The resistance of metal increases when their temperature increases. Certain alloys such as constantan and manganin show very small changes of resistance with temperature and are used to make standard resistors. The resistance of semiconductor and insulator decreases as their temperature increases.



1. The dimensions of a block are $1\,\text{cm} \times 1\,\text{cm} \times 100\,\text{cm}$. If the specific resistance of the material is 3.7×10^{-7} ohm. What is the resistance between two opposite rectangular base?
2. Two wire of the same material have lengths l and $2l$ and areas of cross section 4 A and A respectively. What is the ratio of their specific resistance?
3. A wire of resistance R is stretched to twice of its original length. What is the new resistance of wire?

Ans :

1.

where, $R = \dfrac{\rho l}{A}$

$P = 3.7 \times 10^{-7}$ ohm

$l = 10^{-2}\,\text{m}$

$$= \frac{(3.7 \times 10^{-7} \times 10^{-2})}{1 \times 10^{-2}}$$

$$= 3.7 \times 10^{-7}\,\Omega$$

2. The specific resistance does not depend upon l and A depends upon nature of material. Hence, the specific resistance of both wire remains same.

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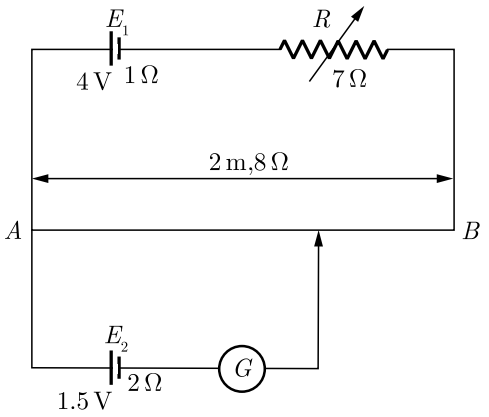
Ans : **Main 2020, 2014**

(i) (a) According to the circuit diagram given, current in the circuit or through the potentiometer wire is



$$I = \frac{E_1}{R_{AB} + R + r_1}$$
$$= \frac{4}{(8+7+1)}$$
$$= \frac{4}{16}\text{ A} = 0.25\text{ A}$$

(b) The potential gradient across the wire AB can be calculated as follows

Resistance of potentiometer wire,

$$R_{AB} = 8\,\Omega$$

Potential difference across the wire,

$$V = IR_{AB}$$
$$= \frac{4}{16} \times 8 = \frac{32}{16} = 2\text{ V}$$

Length of potentiometer wire

$$= 2\text{ m} = 200\text{ cm}$$

Potential gradient,

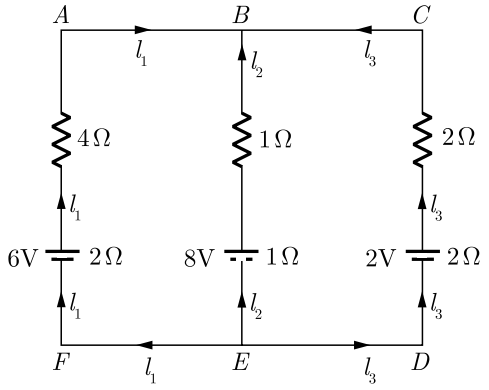
$$K = \frac{V}{l}$$
$$= \frac{2}{200} = 0.01\text{ Vcm}^{-1}$$

(ii) The length AC which is to be calculated for the emf 1.5 V at the balanced point will be

As, $\varepsilon = Kl$

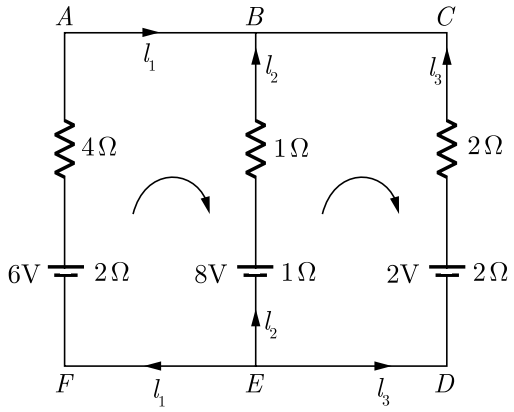
$$l = \frac{\varepsilon}{K} = \frac{1.5}{0.01} = 150\text{ cm}$$

288. Using Kirchhoff's laws of electrical networks, calculate the current I_1, I_2 and I_3 in the circuit shown below



Ans : **SQP 2018, 2016**

After the marking the direction of the current in the circuit and we can draw the following circuit



Applying Kirchhoff's law in loop 1 ($ABEFA$),

$$-6I_1 + 2I_2 - 8 + 6 = 0$$
$$-6I_1 + 2I_2 - 2 = 0$$
$$-6I_1 + 2I_2 = 2$$
$$-3I_1 + I_2 = 1 \quad ...(1)$$

Applying Kirchhoff's law in loop 1 ($BCDEB$),

$$+4I_3 - 2 + 8 - 2I_2 = 0$$
$$4I_3 - 2I_2 + 6 = 0$$
$$2I_2 - 4I_3 = 6$$
$$I_2 - 2I_3 = 3 \quad ...(2)$$

Applying KCL, $I_1 + I_2 + I_3 = 0$

$$I_1 + I_2 = -I_3$$

Solving Eqs. (1) and (2), we get

$$I_2 - 2(I_1 + I_2) = 3$$
$$I_2 - 2I_1 - 2I_2 = 3$$
$$-2I_1 - I_2 = 3 \quad ...(3)$$

After solving equation (1) and (3), we get

$$-3I_1 + I_2 = 1$$
$$-2I_1 - I_2 = 3$$
$$-5I_1 = 4$$

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$$I_1 = -\frac{4}{5}\,\text{A}$$

$$I_2 = 2I_1 - 3 = 2\left(-\frac{4}{5}\right) - 3$$

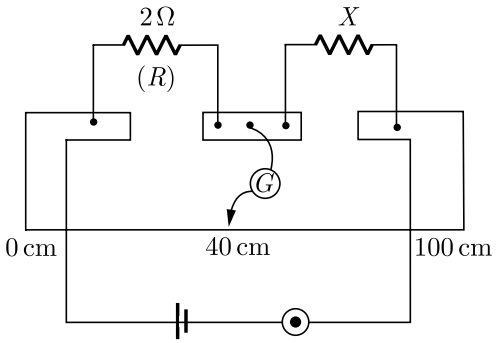
$$= \frac{-8}{5} - 3 = \frac{-23}{5}\,\text{A}$$

and $$I_3 = -(I_1 + I_2)$$

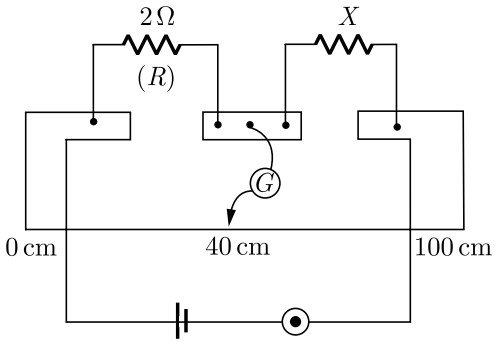
$$= \frac{+23}{5} + 4/5 = \frac{27}{5}\,\text{A}$$

Negative sign implies I_1 and I_2 are in opposite direction of what we have assumed.

289. In a meter bridge circuit, resistance in the left hand gap is $2\,\Omega$ and an unknown resistance X is in the right hand gap as shown in figure below. The null point is found to be 40 cm from the left end of the wire. What resistance should be connected to X so that the new null point is 50 cm from the left end of the wire?



Ans : **Main 2017**



Applying the condition of balanced Wheatstone bridge,we get

$$\frac{R}{X} = \frac{l}{100 - l}$$

Given, $R = 2\,\Omega$

$$X = ?$$

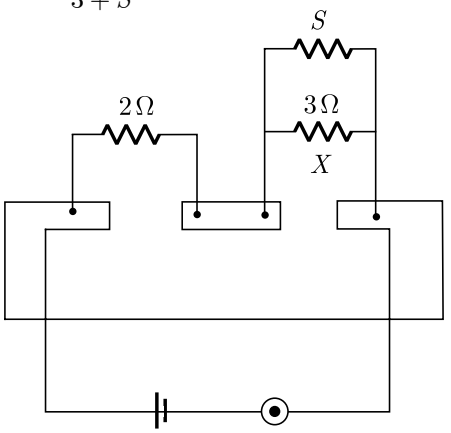
$$l = 40\,\text{cm}$$

$$\frac{2}{X} = \frac{40}{100 - 40}$$

$$\frac{2}{X} = \frac{40}{60}$$

$$X = \frac{2 \times 60}{40} = 3\,\Omega$$

The equivalent resistance of $3\,\Omega$ and $5\,\Omega$ in parallel is $\frac{3S}{3+S}\,\Omega$



Again applying the condition of balanced Wheatstone bridge,

$$\frac{2}{\frac{3s}{3+s}} = \frac{50}{50} = 1$$

$$2 = \frac{3S}{3+S}$$

$$2(3+S) = 3S$$

$$6 + 2S = 3S$$

$$3S - 2S = 6$$

$$S = 6\,\Omega$$

CASE BASED QUESTIONS

290. Most of the times we connect remote speakers to play music in another room along with the built-in-speakers. These speakers are connected in parallel with the music system.

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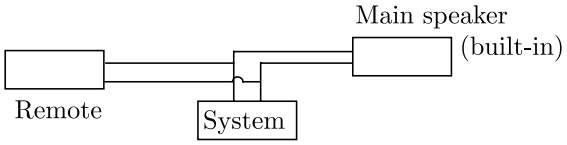
At the instant represented in the picture, the voltage across the speakers is 6.00 V. The resistance of the main speaker is 8 Ω and the remote speaker has resistance 4 Ω

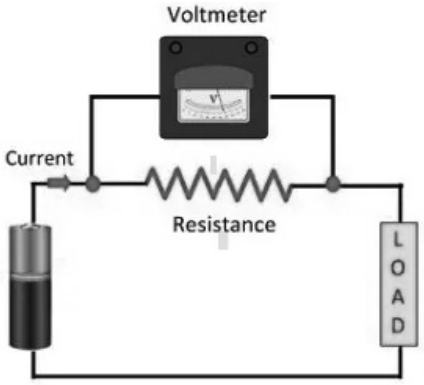


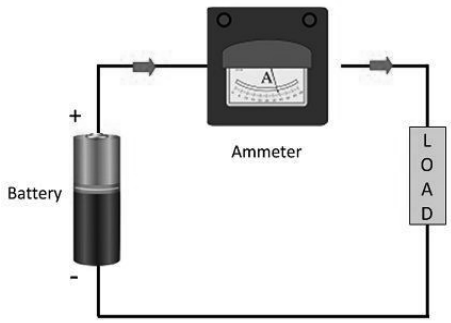
1. What is equivalent resistance of the speakers?
2. What is the total current supplied by music system?
3. What is the power dissipated in the 4 ohm resistance?

Ans :

1. 8/3 ohm
2. 2.25 A
3. 9 W

291. An ammeter and a voltmeter are connected in series to a battery with an emf of 10V. When a certain resistance is connected in parallel with the voltmeter, the reading of the voltmeter decreases three times, whereas the reading of the ammeter increases two times.



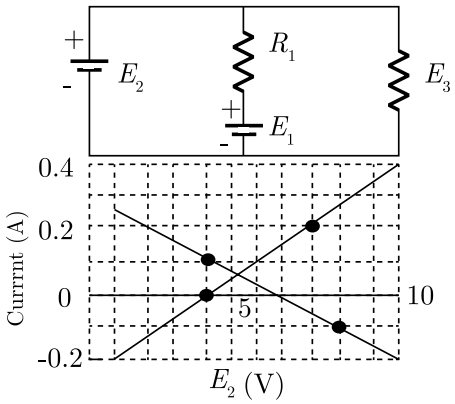


1. Find the voltmeter reading after the connection of the resistance.
2. If the resistance of the ammeter is 2 ohm. What is the resistance of the voltmeter?

Ans :

1. 2 Volt
2. 3 ohm.

292. In the circuit given in the figure, both batteries are ideal, e.m.f. E, of battery I has a fixed valve, but e.m.f. E, of battery 2 can be varied between 1.0 V and 10.0 V. The graph gives the currents through the two batteries as a function of E_2, but are not marked as which plot corresponds to which battery. But for both plots, current is assumed to be negative when the direction of the current through the battery is opposite to the direction of that battery's e.m.f. (direction of e.m.f. is from negative to positive).



1. What is the value of EMF of cell 1?
2. What is the value of resistance R_1?
3. Calculate the value of resistance R_2?

Ans :

1. 4 Volt
2. 10 ohm
3. 10 ohm

293. Electric fuse is a protective device used in series with an electric circuit or an electric appliance to save it from damage due to overheating produced by strong current in the circuit or application. Fuse wire is generally made from an alloy of lead and tin which has high resistance and low melting point. It is connected in series in an electric installation. If a circuit gets accidentally short-circuited, a large current flows, then fuse wire melts every which causes a break in the circuit. The power through fuse (F') is equal to

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CHAPTER 4

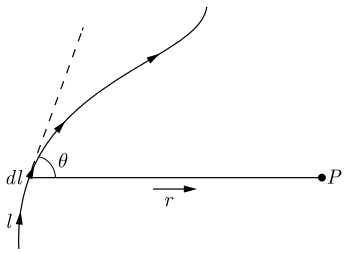
Moving Charge and Magnetism

SUMMARY

1. BIOT-SAVART LAW

It states that the magnetic field strength $\overrightarrow{dB}$ produced to a current element (of current I and length dl) at a point having position vector $\vec{r}$ relative to current element is,

$$\overrightarrow{dB} = \frac{\mu_0}{4\pi}\frac{I\vec{dl} \times \vec{r}}{r^3}$$



Where, $\mu_0 = 4\pi \times 10^{-7}$ Wb/A-meter permeability of free space.

The magnitude of magnetic field is,

$$dB = \frac{\mu_0}{4\pi}\frac{Idl\sin\theta}{r^2}$$

where, θ is the angle between current element $I\ \overrightarrow{dl}$ and position vector $\vec{r}$ as shown in the figure. The direction of magnetic field $\overrightarrow{dB}$ is perpendicular to the plane containing $I\ \overrightarrow{dl}$ and $\vec{r}$.

Magnetic field at the centre of a circular current carrying conductor/coil.

$$B = \frac{\mu_0 I}{2r}$$

where, r is the radius of a circular loop.

For N turns of coil,

$$B = \frac{\mu_0 NI}{2r}$$

Magnetic field at the centre of semi-circular current carrying conductor.

$$B = \frac{\mu_0 I}{4r}$$

Magnetic field at the centre of an arc of circular current carrying conductor which subtends an angle θ at the centre.

$$B = \frac{\mu_0}{4\pi} \cdot \frac{I\theta}{r}$$

Magnetic field at any point lies on the axis of circular current carrying conductor.

$$B = \frac{\mu_0 Ia^2}{2(r^2 + a^2)^{3/2}}$$

2. AMPERE'S CIRCUITAL LAW

It states that the line integral of magnetic field $\vec{B}$ along a closed path is equal to μ_0 times the current (I) passing through the closed path.

$$\oint \vec{B} \cdot \overrightarrow{dl} = \mu_0 I$$

3. MAGNETIC FIELD DUE TO A CURRENT CARRYING SOLENOID

At the axis of a long solenoid, carrying a current I,

$$B = \mu_0 nI$$

where, n = number of turns per unit length

Magnetic field at one end of solenoid,

$$B_{\text{end}} = \frac{\mu_0 nI}{2}$$

The polarity of any end is determined by using Ampere's right hand rule.

4. MAGNETIC FIELD DUE TO A TOROID (CIRCULAR SOLENOID)

Magnetic field within the turns of toroid,

$$B = \frac{\mu_0 NI}{2\pi r} = n\mu_0 I$$

where, $n = \frac{N}{2\pi r}$ and r is average radius

Magnetic field outside the toroid is zero.

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3. $$\frac{R_2}{R_1} = \frac{12 \times A_1}{11 \times A_2}$$

when stretch volume remains constant hence

$$l_1 A_1 = l_2 \times A_2$$

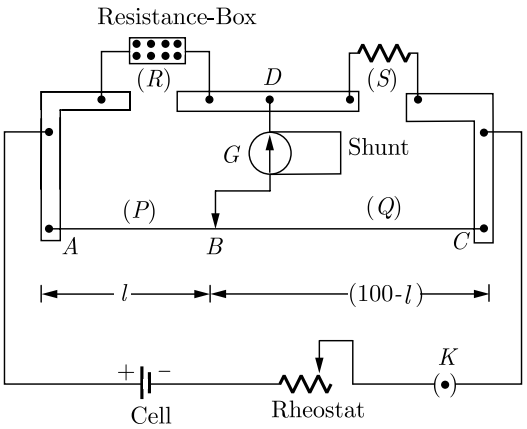
$$\frac{A_1}{A_2} = \frac{l_2}{l_1}$$

$$\frac{A_1}{A_2} = \frac{2}{1}$$

Hence, $$\frac{R_2}{R_1} = \left(\frac{l_2}{l_1}\right) \times \frac{A_1}{A_2}$$

$$= 2 \times 2 = 4$$

295. Meter bridge is a sensitive device based on the principle of Wheatstone's bridge, for the determination of the resistance of a conductor (wire). Its sensitivity is much more than that of the post-office box.



Meter bridge AC is a 1 metre wire of manganin or constantan which is fixed along a scale on a wooden base. The area of cross-section of the wire is same at all places. The ends A and C of the wire are joined to two L-shaped copper strips carrying binding-screws as shown. In between these strips, leaving a gap on either side, there is a third copper strip having three binding screws. The middle screw D is connected to a sliding jockey B through a shunted-galvanometer G. The knob of the jockey can be made to touch at any point on the wire.

(i) What do you mean by Meter bridge?

(ii) At which condition the value of R and S becomes same?

(iii) Write the construction of Meter bridge.

(iv) What are the applications of Meter bridge?

(v) What are the advantages of Meter bridge?

Ans :

(i) A meter-bridge is an instrument that works on the principle of a Wheatstone bridge. It is also known as slide wire bridge.

(ii) The value of resistance R and resistance S is same when the length of AB and BC both are same.

$$\frac{P}{Q} = \frac{R}{S}$$

As, P and Q are same

$$1 = \frac{R}{S}$$

$$S = R$$

(iii) In metre-bridge AC is a 1 m wire of maganin or constantan which is fixed along a scale on a wooden base. The area of cross-section of the wire is same at all places. The ends A and C of the wire are joined to two L-shaped copper strips carrying binding-screws as shown in figure.

(iv) Finding the unknown resistance of a conductor as that of in a wheatstone bridge.

(v) Advantages of meter-bridge are following

(a) To find the unknown resistance very-very accurately.

(b) Directly applied in ammeter or voltmeter. So, resistance offered by ammeter and voltmeter do not effect the readings.

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(ii) Hence, current in circuit,

$$I_1 = \frac{E}{R_{eq}} = \frac{10\text{V}}{10\Omega} = 1\,\Omega$$

For closed loop ACB, applying KVL,

$$15I_2 - 30L_4 = 0$$

$$I_2 = 2I_4 \qquad ...(1)$$

For closed loop $GABFG$, applying KVL,

$$4I_1 + 15I_2 = 10$$

$$4 \times 1 + 15I_2 = 10$$

$$I_2 = \frac{6}{15} = 0.4 \text{ A} \qquad ...(2)$$

Using (1) and (2), $I_4 = 0.2$ A

Now at point A, applying KCL,

$$I_1 = I_2 + I_3 + I_4$$

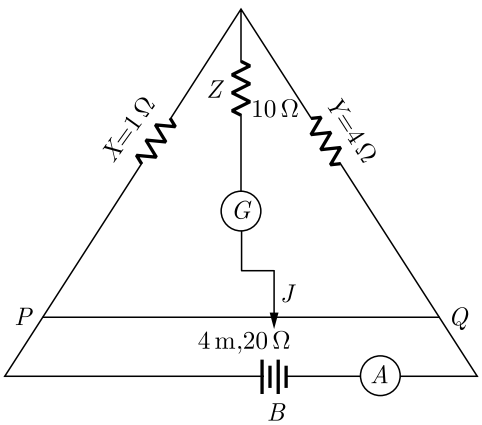
$$I_3 = I_1 - I_2 - I_4$$

$$= 1 - 0.4 - 0.2 = 0.4 \text{ A}$$

so, $I_1 = 1\text{A}$, $I_2 = 0.4\text{A}$,

$I_3 = 0.4\text{A}$, $I_4 = 0.2\text{A}$

286. In the circuit shown alongside, PQ is a uniform metallic wire of length 4 m and resistance $20\,\Omega$. Battery B has an emf of 10 V and internal resistance of $1\,\Omega$. J is a jockey or slide contact. Resistance of the ammeter A and connecting wires is negligible.



(i) When the jockey J does not touch the wire PQ, what is the reading of ammeter A?

(ii) Where should the jockey J be pressed on the wire PQ, so that the galvanometer G shows no deflection?

Ans : **Main 2010**

For no deflection in the galvanometer the bridge should be balanced.

(i) When jockey does not touch the wire PQ, $10\,\Omega$ is not connected.

In upper arm of PQ,

Resistances $X + Y = 1 + 4 = 5\,\Omega$ [for series combination]

$20\,\Omega$ and $5\,\Omega$ are in parallel.

$$R_{\text{Total}} = \frac{20 \times 5}{20 + 5} = \frac{100}{25} = 4\,\Omega$$

Current in circuit, $I = \dfrac{E}{r + R_{\text{Total}}}$

$$= \frac{10}{1 + 4} = 2 \text{ A}$$

(ii) Let the distance of the jockey (J) be x.

Then, by Wheatstone bridge under balanced condition,

$$\frac{X}{Y} = \frac{x}{4 - x}$$

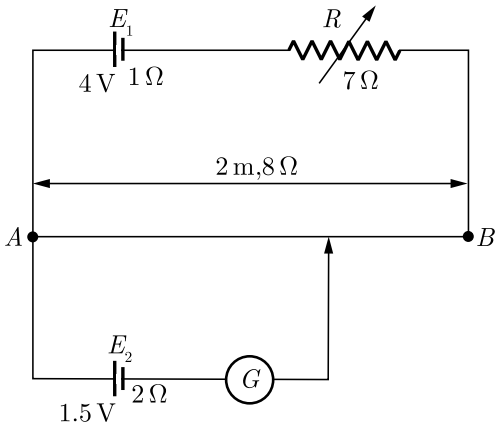
$$\frac{1}{4} = \frac{x}{4 - x}$$

$$4 - x = 4x$$

$$4 = 5x$$

$$x = 0.8 \text{ m}$$

287. A potentiometer circuit is shown in figure below. AB is a uniform metallic wire having length of 2 m and resistance of $8\,\Omega$. The batteries E_1 and E_2 have emfs of 4 V and 1.5 V and their internal resistances are $1\,\Omega$ and $2\,\Omega$ respectively.



(i) When the jockey J does not touch the wire AB, calculate

(a) the current flowing through the potentiometer wire AB.

(b) the potential gradient across the wire AB.

(ii) Now the jockey J is made to touch the wire AB at a point C such that the galvanometer G shows no deflection. Calculate the length AC.

NODIA

5. FORCE ON A MOVING CHARGED PARTICLE IN MAGNETIC FIELD

The force on a charged particle moving with velocity $\vec{v}$ in a uniform magnetic field $\vec{B}$ is given by,

$$\vec{F}_m = q(\vec{v} \times \vec{B})$$

This is known as Lorentz force.

The direction of this force is determined by using Fleming's left hand rule.

The direction of this force is perpendicular to both $\vec{v}$ and $\vec{B}$.When $\vec{v}$ is parallel to $\vec{B}$, then $\vec{F}_m = 0$.

When $\vec{v}$ is perpendicular to $\vec{B}$, then $\vec{F}_m$ is maximum, i.e., $\vec{F}_m = qv\vec{B}$.

SI Unit of Magnetic Field

Since, $F = qvB\sin\theta$

$$B = \frac{F}{qv\sin\theta}$$

If, $F = 1\,\text{N}$

$q = 1\,\text{C}$

$v = 1\,\text{m/s}$

$\sin\theta = 1$

$\theta = 90^\circ$

Hence, SI unit of $B = \dfrac{1\text{N}}{(1\text{C})\,(1\text{m/s})}$

$= 1\,\text{NA}^{-1}\text{m}^{-1}$

$= 1\,\text{T} = 1$ tesla (T)

6. RESONANCE CONDITION FOR THE ACCELERATION OF CHARGED PARTICLES

The frequency of revolution of charged particle must be equal to the frequency of radio frequency voltage source.

The frequency of revolution of the particle is,

$$f = \frac{qB}{2\pi m}$$

where, B is the magnetic field inside the dees, q is the charge on the particle and m is its mass. This frequency is called cyclotron frequency.

Energy gained per revolution $= 2\,qV$

Energy gained in n- revolutions,

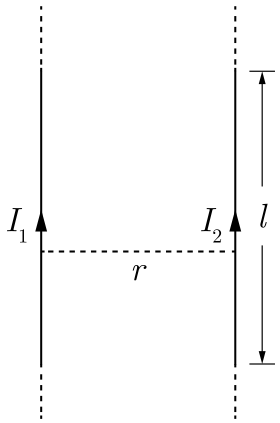
$$E = 2nqV = \frac{B^2q^2R^2}{2m}$$

where, R is radius of circular track of charged particle.

7. MAGNETIC FORCE BETWEEN TWO STRAIGHT PARALLEL CURRENT CARRYING CONDUCTORS IS GIVEN BY

Magnetic force between two straight parallel current carrying conductors is given by

$$\frac{F}{L} = \frac{\mu_0}{4\pi} \cdot \frac{2I_1I_2}{r}$$



Torque Experienced by a Current Loop (of area $\vec{A}$)

Carrying current I in a uniform magnetic field $\vec{B}$ is given by,

$$\vec{\tau} = NI(\vec{A} \times \vec{B})$$

$$= \vec{M} \times \vec{B}$$

where, $\vec{M} = NI\,\vec{A}$ is magnetic moment of loop

The unit of magnetic moment in SI system is ampere $\times$ metre^2(Am^2).

Potential Energy of a Current Loop in a Magnetic Field

When a current loop of magnetic moment M is placed in a magnetic field, then potential energy of magnetic dipole is,

$$U = -\vec{M} \cdot \vec{B}$$

$$= -MB\cos\theta$$

1. When $\theta = 0$, $U = -MB$ (minimum or stable equilibrium position).
2. When $\theta = \pi$, $U = +MB$ (maximum or unstable equilibrium position).
3. When $\theta = \dfrac{\pi}{2}$, potential energy is zero.

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30. The magnitude of magnetic field at a point due to a current-carrying small element does not depend upon

(a) current in the element

(b) length of the element

(c) diameter of the element

(d) distance of the point from the element

Ans : SQP, 2014, 2011

We know from the Biot-Savart's law that magnitude of magnetic field at a point due to a current-carrying small element,

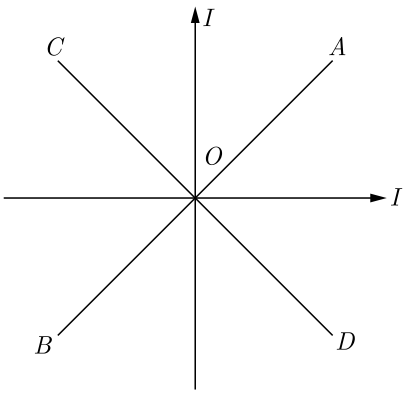
$$(d\vec{B}) = \frac{\mu_0}{4\pi}\frac{i\,dl\sin\theta}{r^2}$$

where $i =$ Current in the element, $l =$ Length of the element and $r =$ Distance of the point from the element.

Therefore, magnitude of magnetic field at a point due to a current-carrying small element does not depend upon the diameter of the element.

Thus (c) is correct option.

31. Two equal electric currents are flowing perpendicular to each other as shown in the figure. AB and CD are perpendicular to each other and symmetrically placed with respect to the currents. Where do we expect the resultant magnetic field to be zero ?



(a) on AB

(b) on CD

(c) on both AB and CD

(d) on both OD and BO

Ans : SQP 2010

The direction of the magnetic field due to current is given by the Right-hand thumb rule.

Since, the components of magnetic field due to two electric currents on the axis AB cancel each other, therefore, the resultant magnetic field on AB will be zero.

Thus (a) is correct option.

32. An electric current passes through a long straight copper wire. At a distance 5 cm from the straight wire, the magnetic field is B. The magnetic field at 20 cm from the straight wire would be

(a) $\frac{B}{6}$ (b) $\frac{B}{4}$

(c) $\frac{B}{3}$ (d) $\frac{B}{2}$

Ans : Main 2017

Given,

Distance of first point from the wire,

$$r_1 = 5\,\text{cm}$$

Magnetic field at first point,

$$B_1 = B$$

and distance of second point from the wire,

$$r_2 = 20\,\text{cm}$$

magnetic field due to current-carrying long straight wire at the point,

$$B = \frac{\mu_0}{2\pi}\times\frac{I}{r} \propto \frac{1}{r}$$

Therefore, $$\frac{B_1}{B_2} = \frac{r_2}{r_1} = \frac{20}{5} = 4$$

$$B_2 = \frac{B_1}{4} = \frac{B}{4}$$

where, $B_2 =$ magnetic field at second point

Thus (b) is correct option.

33. Two circular coils of diameters 10 cm and 20 cm have the same no. of turns and currents. The ratio of magnetic field inductions produced at the centre of the coils, when connected in series is

(a) 1 : 2 (b) 2 : 1

(c) 3 : 2 (d) 2 : 3

Ans : Main 2006

Given,

Diameter of first coil, $d_1 = 10\,\text{cm}$

Radius of first coil, $r_1 = 5\,\text{cm}$

Diameter of second coil, $d_2 = 20\,\text{cm}$

Radius of second coil, $r_2 = 10\,\text{cm}$

Magnetic field induction produced at the centre of a current-carrying circular coil,

$$B = \frac{\mu_0 nI}{2r} \propto \frac{1}{r}$$

Therefore, $$\frac{B_1}{B_2} = \frac{r_2}{r_1} = \frac{10}{5}$$

$$B_1 : B_2 = 2:1$$

Thus (b) is correct option.

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Ans : **Main 2023**

The magnetic field at the centre of a circular coil carrying current is given by the formula

$$B = \mu_0 NI/2r$$

where , μ_o is the permeability of free space, N is the number of turns, I is the current, and iis the radius of the coil.

Thus (b) is correct option.

2. Magnetic flux density of the magnetic field at a point on the axis of a long straight solenoid is given by

(a) $B = \mu_0 nI$ (b) $B = \frac{\mu_0 I}{2r}$

(c) $B = \frac{\mu_0 I}{4\pi r}$ (d) $B = \mu_0 I$

Ans : **SQP 2023**

For a long straight solenoid, the magnetic flux density on its axis is given by:

$$B = \mu_0 nI$$

Where,

μ_o = permeability of free space

n = number of turns per unit length

I = current through the solenoid

Thus (a) is correct option.

3. What is the SI (base unit) unit of permeability?

(a) kg-ms^{-2}A^{-2} (b) kg-m^{2}s^{-2}A^{-2}

(c) kg-m^{2}sA^{-2} (d) kg-ms^{2}A^{-2}

Ans : **Main 2022 Sem-I**

$$\mu_0 = \frac{\text{Newton}}{\text{Ampere}^2} = \frac{\text{kg} - \text{ms}^{-2}}{\text{A}^2}$$
$$= \text{kg} - \text{ms}^{-2}\text{A}^{-2}$$

Thus (a) is correct option.

4. What is the locus of an electron, projected perpendicular to a uniform magnetic field?

(a) Circle (b) Right bisector

(c) Parabola (d) Straight line

Ans : **Main 2022 Sem-I**

When a charged particle (like an electron) is projected perpendicular to a uniform magnetic field, the magnetic force acts as a centripetal force, causing the particle to move in a circular path.

Thus (a) is correct option.

5. Magnetic field B at a point on the axis of (and inside) a long current carrying solenoid is given by

(a) $2\mu NI/l\pi$ (b) $\mu NI/l\pi$

(c) $\mu NI/l$ (d) $\mu NI/2l$

Ans : **Main 2022 Sem-I**

Magnetic field at a point inside on the axis of a solenoid in a given medium is $B = \mu nI$,

Where n = number of turns per

$$\text{Unit length} = \frac{N}{l}$$
$$B = \mu NI/l$$

Thus (c) is correct option.

6. Which of the following is the right expression to define the magnetic field B ?

(a) $\vec{F} = q(\vec{v} \times \vec{B})$ (b) $\vec{F} = B(\vec{I} \times l)$

(c) $\frac{\vec{F}}{l} = \frac{\mu_0}{2\pi}\frac{I^2}{a}$ (d) $B = \mu_0 ni$

Ans : **Main 2022 Sem-I**

$$\vec{F} = q(\vec{v} \times \vec{B})$$

This is the right expression to define magnetic field B.

Thus (a) is correct option.

7. A charge moving with uniform velocity produces

(a) only an electric field

(b) only a magnetic field

(c) electromagnetic field

(d) none of these

Ans : **Main 2021, 2015**

A moving charge is produces electric and magnetic field. Hence, a electromagnetic field is present around a moving charge. Thus (c) is correct option.

8. The coil of a moving coil galvanometer is wound over a metal frame in order to

(a) reduce hysteresis

(b) increase sensitivity

(c) increase moment of inertia

(d) provide electromagnetic damping

Ans : **SQP 2017**

The coil of a moving coil galvanometer is wound over a metal frame, in order to provide electromagnetic damping, so that the galvanometer becomes dead beat i.e., on passing current, galvanometer shows a steady deflection without any oscillation. Thus (d) is correct option.

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20. A long straight wire of radius 'a' carries a steady current I. The current is uniformly distributed across its area of cross-section. The ratio of magnitude of magnetic field $\vec{B}$ at $\frac{a}{2}$ and $\vec{B}_2$ at distance $2a$ is

(a) $\frac{1}{2}$ (b) 1

(c) 2 (d) 4

Ans : **Comp 2023**

Consider two American loops of radius $a/2$ and $2a$.

Applying ampere's circuital law for these loops, we get

$$\oint B.dL = \mu_0 I_{\text{enclosed}}$$

For the smaller loop,

$$B_1 \times 2\pi\frac{a}{2} = \mu_0 \times \frac{1}{\pi a^2} \times \left(\frac{a}{2}\right)^2$$

$$\mu_0 I \times \frac{1}{4} = \frac{\mu_0 I}{4}$$

$$B_1 = \frac{\mu_0 I}{4\pi a}$$

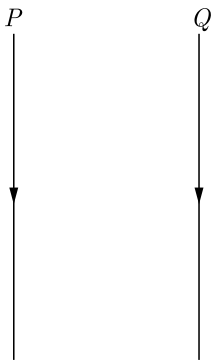
and for bigger loop,

$$B_2 = \frac{\mu_0 I}{2\pi(2a)} \quad \frac{\mu_0 I}{4\pi a}$$

$$\frac{B_1}{B_2} = 1$$

Thus (b) is correct option.

21. Two long straight wires P and Q are parallel to each other. They carry currents in the same direction as shown in the figure. The wire P is kept fixed, then the wire Q will



(a) also remain at rest

(b) move towards the wire P

(c) move away from the wire P

(d) come out of the plane of this paper

Ans : **Main 2022 Sem-I**

Thus (b) is correct option.

22. A charge q moves in a region where electric field $\vec{E}$ and magnetic field $\vec{B}$ both exist, then force on its is

(a) $q(\vec{v} \times \vec{E})$ (b) $q\vec{E}$

(c) $q\{\vec{E} + (\vec{v} \times \vec{B})\}$ (d) $q\{\vec{B} + (\vec{v} \times \vec{E})\}$

Ans : **Main 2011**

A charge q in an electric field $\vec{E}$ experiences the electric force,

$$\vec{F}_e = q\vec{E} \qquad ...(1)$$

The magnetic force experienced by the charge q moving with velocity $\vec{v}$ in the magnetic field $\vec{B}$ is given by,

$$\vec{F}_m = q(\vec{v} \times \vec{B}) \qquad ...(2)$$

Total force, $F = \vec{F}_e + \vec{F}_m$

$$= qE + q(\vec{v} \times \vec{B})$$

$$= q\{\vec{E} + (\vec{v} \times \vec{B})\}$$

Thus (c) is correct option.

23. A circular coil of radius r carries a current I. The magnetic field at its centre is B. At what distance from the centre, on the axis of the coil, the magnetic field will be $B/8$

(a) $\sqrt{2}\,R$ (b) $2R$

(c) $\sqrt{3}\,R$ (d) $3R$

Ans : **Main 2004**

According to the question,

Magnetic field at distance x from the centre,

$$B_{\text{axis}} = \frac{\text{magnetic field at center}\,(B)}{8}$$

$$B_{\text{axis}} = \frac{B}{8}$$

$$\frac{\mu_0 NiR^2}{2(R^2+x^2)^{3/2}} = \frac{\mu_0 Ni}{8 \times 2R}$$

$$8R^3 = (R^2+x^2)^{3/2}$$

This is possible only when $x = \pm\sqrt{3}\,R$.

Hence, $\sqrt{3}\,R$ distance from the centre magnetic field is equal to magnetic field at centre.

Thus (c) is correct option.

24. When a charged particle moves perpendicular to a magnetic field, then

(a) speed of the particle is changed.

(b) speed of the particle remains unchanged.

(c) direction of the particle remains unchanged.

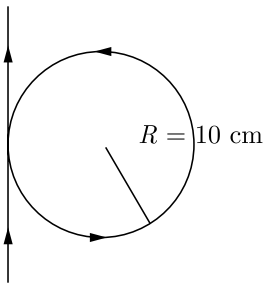
(d) acceleration of the particle remains unchanged.

$$(d\vec{B}) = \frac{\mu_0}{4\pi} i\left(\frac{\vec{dl} \times \vec{r}}{r^3}\right)$$

and the direction of magnetic field $(d\vec{B})$ is given by Right-hand thumb rule.

Thus (c) is correct option.

16. A straight long wire is turned into a loop of radius $R = 10\,\text{cm}$, as shown in figure below. If a current $I = 16\,\text{A}$ is passed through the wire, then the magnetic field at the centre of the loop is



(a) $3.4 \times 10^{-5}\,\text{T}$ (b) $6.8 \times 10^{-5}\,\text{T}$

(c) $1.7 \times 10^{-5}\,\text{T}$ (d) $5.1 \times 10^{-5}\,\text{T}$

Ans : Main 2022 Sem-I

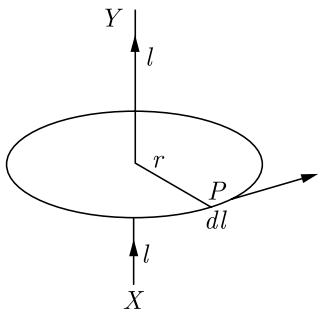
$$B = \frac{\mu_0}{4\pi} \cdot \frac{2I}{r} = \frac{\mu_0 I}{2\pi r}$$

$$= \frac{\mu_0 i}{2r}\left(\frac{1}{\pi} - 1\right) = \frac{4\pi \times 10^{-7}}{2 \times 10^{-1}} \times \left(\frac{1}{3.14} - 1\right)$$

$$= 6.8 \times 10^{-5}\,\text{T} \text{ (outward direction)}$$

Thus (b) is correct option.

17. What is the angle between the current element $d\vec{I}$ and the magnetic flux density $\vec{B}$ at point P in the figure given below?



(a) Parallel to each other

(b) Perpendicular to each other

(c) Normal to each other

(d) Any angle between them is possible

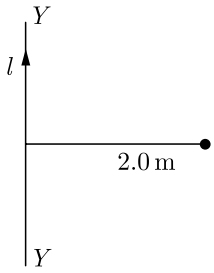
Ans : Main 2022 Sem-I

The current element $d\vec{l}$ and magnetic flux density $\vec{B}$ at any point P are always tangential to each other.

Thus (a) is correct option.

18. The point P is at a perpendicular distance of 0.2 m from a long straight wire YY', which carries a current of 1.6 A, as shown in figure.

Magnetic flux density of the magnetic field at point P is



(a) $1.6 \times 10^{-6}\,\text{T}$ directed into the paper

(b) $1.6 \times 10^{-6}\,\text{T}$ coming out of the paper

(c) $0.8 \times 10^{-6}\,\text{T}$ directed into the paper

(d) $0.8 \times 10^{-6}\,\text{T}$ coming out of the paper

Ans : Main 2024 Sem-I

Magnetic field due to long straight wire,

$$B = \frac{\mu_0}{4\pi} \cdot \frac{i}{d} \times 2 = 10^{-7} \times \frac{1.6}{0.2} \times 2$$

$$= 1.6 \times 10^{-6}\,\text{T}, \text{ directed into the paper}$$

Thus (a) is correct option.

19. A circular coil carrying a current I has radius R and the number of turns N. All the three, i.e. the current I, radius R and number of turns N are doubled, then magnetic field at its centre becomes

(a) double (b) half

(c) four times (d) one-fourth

Ans : Main 2018

Magnetic field at the centre of a current carrying coil is given by

$$B = \frac{\mu_0 NI}{2R} \quad \ldots(1)$$

If $I' = 2I,\ R' = 2R,\ N' = 2N$, then

Magnetic field,

$$B' = \frac{\mu_0 N' I'}{2R'} = \frac{\mu_0 (2N)(2I)}{2(2R)}$$

$$B' = 2\left(\frac{\mu_0 NI}{2R}\right)$$

$$B' = 2B \quad \text{[from Eq. (1)]}$$

Thus (a) is correct option.

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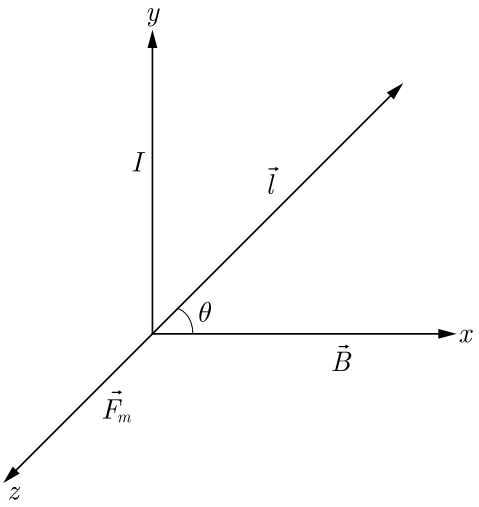
8. MAGNETIC FORCE ON A CURRENT CARRYING CONDUCTOR



Magnetic force on a current carrying conductor of length (l) is given by

$$\vec{F}_m = I(\vec{l} \times \vec{B})$$

Magnitude of force is,

$$F_m = IlB\sin\theta$$

Direction of force $\vec{F}$ is normal to $\vec{l}$ and $\vec{B}$ given by Fleming's Left Hand Rule. If $\theta = 0$ (i.e., $\vec{l}$ is parallel to $\vec{B}$), then magnetic force is zero.

9. MOVING COIL GALVANOMETER

Is a device used to detect the current in electrical circuit. It is based on the principle that a current carrying loop placed in a uniform magnetic field experiences torque. The current sensitivity and voltage sensitivity and voltage sensitivity of galvanometer depends on number of turns of coil magnetic field B, area A of the coil and torsion constant k of the spring or suspension wire.

Current sensitivity, $I_s = \frac{\theta}{I} = \frac{NBA}{k}$

Its SI unit is rad/A or div/A.

Voltage sensitivity, $V_s = \frac{\theta}{V} = \frac{\theta}{IR}$

$$= \frac{I_s}{R} = \frac{NBA}{kR}$$

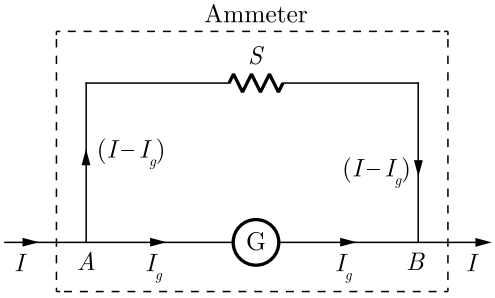
Its SI unit is rad/V or div/V.

Torque or moment of galvanometer,

$$G = \frac{\theta}{I} = \frac{NBA}{k}$$

A galvanometer can be converted into an ammeter by connecting a very low resistance (shunt S) in parallel with galvanometer whose value is given by,

$$S = \frac{I_g G}{I - I_g}$$



where, G = Resistance of galvanometer

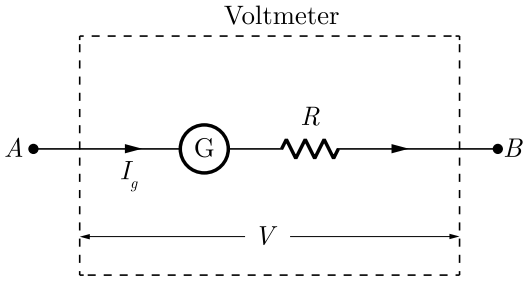
I_g = Current through galvanometer

I = Total current in circuit

S = resistance of the shunt (low resistance)

A galvanometer can be converted into voltmeter by connecting a very high resistance R in series with galvanometer which is given by

$$R = \frac{V}{I_g} - G$$



where,

I_g = current through the galvanometer

G = resistance of galvanometer and

V = potential difference across the terminal A and B

****

OBJECTIVE QUESTIONS

1. A circular coil has radius r, number of turns N and carries a current I, magnetic flux density B at its centre is

(a) $\mu_0 NI$ (b) $\mu_0 NI/2r$

(c) $\mu_0 NI/4\pi r$ (d) $\mu_0 NI/4r$

Ans : SQP 2009, 2005

when a charged particle moves perpendicular to a magnetic field, then the particle moves in a circular path with a uniform speed.

As a result of this, the particle experiences a centripetal force, but the speed of the particle remains unchanged.

Thus (b) is correct option.

25. A charged particle is released from rest in a region of steady and uniform electric and magnetic fields, which are parallel to each other. The particle will move in a

(a) circle (b) helix

(c) cycloid (d) straight line

Ans : SQP 2025

When a charged particle is released from rest in a region of steady and uniform electric and magnetic fields, which are parallel to each other, then charged particle will move along the electric field in a straight line, because magnetic field has no effect on it.

Thus (d) is correct option.

26. The dimensional formula for $\frac{1}{2}\varepsilon_0 E^2$ is identical to that of

(a) $\frac{B^2}{2\mu_0}$ (b) $\frac{1}{2}B^2\mu_0$

(c) $\frac{\mu_0^2}{2B}$ (d) $\frac{1}{2}B\mu_0^2$

Ans : Main 2010

Dimension of $\frac{1}{2}\varepsilon_0 E^2$ is given by,

$$\frac{1}{2}\varepsilon_0 E^2 = \frac{\text{Energy}}{\text{Volume}}$$

$$= \frac{[\mathrm{ML^2T^{-2}}]}{[\mathrm{L^3}]} = [\mathrm{ML^{-1}T^{-2}}]$$

Dimension of $\frac{B^2}{2\mu_0}$ is given by,

$$= \frac{[\mathrm{MT^{-2}A^{-1}}]^2}{[\mathrm{MLT^{-2}A^{-2}}]}$$

$$\left[\text{Since, } B = \tfrac{F}{qV\sin\theta}, \mu_0 = \tfrac{4\pi r F}{I_1 I l}\right]$$

$$= [\mathrm{M^1L^{-1}T^{-2}}]$$

Thus (a) is correct option.

27. If a current i ampere flows in a long straight thin walled tube, then magnetic induction at any point inside the tube is

(a) zero (b) infinite

(c) $\frac{2i}{r}$ Tesla (d) $\frac{\mu_0}{4\pi}\cdot\frac{2i}{r}$ Tesla

Ans : Main 2008

Given,

Current in the long straight thin walled tube $= i$.

current flows only on the surface of a long straight thin walled tube.

Therefore, magnetic induction at any point inside the tube is zero.

Thus (a) is correct option.

28. Magnetic field due to a long straight conductor of length l, carrying current I, at a point, distance d from it is given by

(a) $B = \frac{\mu_0}{4\pi} \times \frac{2I}{d}$ (b) $B = \frac{\mu_0}{4\pi} \times \frac{I}{d}$

(c) $B = \frac{\mu_0}{4\pi} \times \frac{2I}{d^2}$ (d) $B = \frac{\mu_0}{\pi} \times \frac{2I}{d}$

Ans : SQP 2024

Given,

Length of the straight conductor $= l$

Current in the conductor $= I$

and distance of the point from it $= d$

We know the magnetic field at a point due to a long current-carrying conductor,

$$B = \frac{\mu_0}{4\pi} \times \frac{2I}{d}$$

where, $\mu_0 =$ absolute permeability of free space.

Thus (a) is correct option.

29. At what distance of a point, from a long straight wire carrying a current of 12 A will the magnetic field be equal to 3×10^{-5} T ?

(a) 8 cm (b) 16 cm

(c) 32 cm (d) 64 cm

Ans : Main 2015

Given

Current in wire, $I = 12$ A

and Magnetic field, $B = 3 \times 10^{-5}$ T

distance of the point from the wire,

$$r = \frac{\mu_0}{2\pi} \times \frac{I}{B}$$

$$= \frac{4\pi \times 10^{-7}}{2\pi} \times \frac{12}{3 \times 10^{-5}}$$

$$= 8 \times 10^{-2}\,\mathrm{m} = 8\,\mathrm{cm}$$

where $\mu_0 =$ absolute permeability of free space

equal to $4\pi \times 10^{-7}\,\mathrm{WbA^{-1}m^{-1}}$

Thus (a) is correct option.

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9. A proton is moving in a uniform magnetic field B with a velocity v at an angle θ with the field. The force acting on the proton is minimum, when θ is

(a) 120° (b) 90°

(c) 60° (d) 0°

Ans : **Main 2022 Sem-I**

$$\vec{F} = q(\vec{v} \times \vec{B})$$

$$F = qvB\sin\theta$$

For F to be minimum, $F = 0$

i.e., $\sin\theta = 0$

$\theta = 0^\circ$

Thus (d) is correct option.

10. A moving electron centres a uniform and perpendicular magnetic field. Inside the magnetic field, the electron travels along

(a) a straight line (b) a parabola

(c) a circle (d) a hyperbola

Ans : **Main 2025, 2016**

According to right hand thumb rule, the electron travels along a circle. Since, the right hand thumb rule states that "when a force is perpendicular to velocity and hence it changes its path continuously and this force acts as a centripetal force and produces a circular motion perpendicular to the magnetic field.

Thus (c) is correct option.

11. Choose the correct option of The Biot-Savart's law in vector form is

(a) $d\vec{B} = \frac{\mu_0}{4\pi}\frac{d\vec{I}(I \times r)}{\vec{r}^3}$

(b) $d\vec{B} = \frac{\mu_0}{4\pi}\frac{I(d\vec{I} \times \vec{r})}{\vec{r}^3}$

(c) $d\vec{B} = \frac{\mu_0}{4\pi}\frac{I(\vec{r} \times d\vec{I})}{\vec{r}^3}$

(d) $d\vec{B} = \frac{\mu_0}{4\pi}\frac{I(d\vec{I} \times \vec{r})}{\vec{r}^2}$

Ans : **Main 2013**

Biot-Savart's law in vector form is

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{I(d\vec{l} \times \vec{r})}{r^3}$$

Thus (b) is correct option.

12. Choose the correct option of The Biot-Savart's law in vector form is

(a) $d\vec{B} = \frac{\mu_0}{4\pi}\frac{d\vec{I}(I \times r)}{\vec{r}^3}$

(b) $d\vec{B} = \frac{\mu_0}{4\pi}\frac{I(d\vec{I} \times \vec{r})}{\vec{r}^3}$

(c) $d\vec{B} = \frac{\mu_0}{4\pi}\frac{I(\vec{r} \times d\vec{I})}{\vec{r}^3}$

(d) $d\vec{B} = \frac{\mu_0}{4\pi}\frac{I(d\vec{I} \times \vec{r})}{\vec{r}^2}$

Ans : **Main 2013**

Biot-Savart's law in vector form is

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{I(d\vec{l} \times \vec{r})}{r^3}$$

Thus (b) is correct option.

13. A proton is moving in a space with constant velocity in an electric field E and magnetic field B. The angle between electric field and magnetic field should be

(a) 0° (b) 30°

(c) 45° (d) 90°

Ans : **SQP 2007**

when a charged particle (i.e., proton) is moving in space with a constant velocity in electric field E and magnetic field B, then angle between electric field and magnetic field should be 90°.

Thus (d) is correct option.

14. Dimension of magnetic field is

(a) $I^{-1}ML^0T^{-2}$ (b) I^0MLT^{-2}

(c) $IMLT^{-1}$ (d) $IM^{-1}L^{-1}T^{-2}$

Ans : **SQP 2010**

$$F = qvB\sin\theta$$

$$B = \frac{F}{qv\sin\theta}$$

$\sin\theta$ is a dimensionless quantity

$$= \frac{[M^1L^1T^{-2}]}{[IT]\,[LT^{-1}]} \qquad [\text{Since, } q = IT]$$

$$= [ML^0T^{-2}I^{-1}]$$

Thus (a) is correct option.

15. The direction of magnetic field produced by a current-carrying small element of any shape is given by

(a) Lenz law

(b) Newton's law

(c) Right-hand thumb rule

(d) Fleming left-hand rule

Ans : **SQP 2008**

Magnetic field produced by a current-carrying small element of any shape,

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34. The magnetic field induction at one end on the axis of a long solenoid having n turns per unit length and carrying I ampere current is

(a) $\mu_0 nI$ (b) $\frac{\mu_0 nI}{2}$

(c) $\frac{\mu_0 nI}{4}$ (d) zero

Ans : **Comp 2002**

Given,

Number of turns per unit length $= n$

and Current in solenoid $= I$

magnetic field induction at one end of a long solenoid,

$$B = \frac{\mu_0 nI}{2}$$

where, $\mu_0 =$ Absolute permeability of free space

Thus (b) is correct option.

35. A uniform electric field and a uniform magnetic field are acting along the same direction in a certain region. If an electron is projected along the direction of the fields with a certain velocity, then

(a) its velocity will increase.

(b) its velocity will decrease.

(c) it will turn towards left.

(d) it will turn towards right.

Ans : **Main 2017**

When an electron is projected in a region of uniform electric and magnetic fields acting along the same direction, then electric field will apply force on the electron in the opposite direction to the motion, whereas magnetic field will not apply any force on the electron. Thus the electron experiences retardation.

As a result of this, velocity of the electron will decrease.

Thus (b) is correct option.

36. A current-carrying coil is placed in a uniform magnetic field of induction B. The current in the coil is I, it has n turns and A is the face area of coil and normal to the surface makes an angle θ with B. The torque experienced by the coil is

(a) $nIAB\theta$ (b) $nIAB\cos\theta$

(c) $nIAB\sin\theta$ (d) $nIAB\tan\theta$

Ans : **SQP 2001**

Magnetic field induction $= B$

Current in coil $= I$

Numbers of turns in coil $= n$

Area of coil $= A$

and angle between normal to the surface of coil and magnetic field $= \theta$.

Torque experienced by the coil,

$$\tau = nIAB\sin\theta$$

Thus (c) is correct option.

37. Two solenoids of the same length having number of turns in the ratio of 2 : 3 are connected in series. The ratio of magnetic fields at their centres is

(a) 2 : 1 (b) 3 : 1

(c) 2 : 3 (d) 3 : 2

Ans : **Main 2012**

Given,

Number of turns in first solenoid, $N_1 = 2N$

No. of turns in second solenoid, $N_2 = 3N$

Number of turns per unit length,

$$n = \frac{N}{L}$$

Where, $L =$ length of solenoid

The magnetic field at the centre of solenoid,

$$B = \mu_0 nI$$

$$= \mu_0\left(\frac{N}{L}\right)I \propto N$$

Therefore, $\frac{B_1}{B_2} = \frac{N_1}{N_2} = \frac{2N}{3N} = \frac{2}{3}$

$$B_1 : B_2 = 2 : 3$$

Thus (c) is correct option.

38. A long solenoid has 800 turns per meter length of solenoid. A current of 1.6 A flows through it. The magnetic field induction at the end of the solenoid on its axis is

(a) 4×10^{-4} T (b) 8×10^{-4} T

(c) 16×10^{-4} T (d) 32×10^{-4} T

Ans : **Main 2009, 2002**

Number of turns per metre length,

$$n = 800$$

Current in solenoid, $I = 1.6$ A

Magnetic field induction at the end of the solenoid on its axis,

$$B = \frac{\mu_0 nI}{2}$$

(where $\mu_0 =$ Absolute permeability of free space equal to $4\pi \times 10^{-7}$ Wb $-$ A$^{-1}-$ m^{-1})

$$= \frac{(4\pi \times 10^{-7}) \times 800 \times 1.6}{2}$$

$$= 8.038 \times 10^{-4} \approx 8 \times 10^{-4} \text{ T}$$

Thus (b) is correct option.

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39. Two long straight parallel conductors separated by a distance of 0.5 m carry currents of 5 A and 8 A in the same direction. The force per unit length experienced by each other is

(a) 1.6×10^{-5} N (attractive)

(b) 1.6×10^{-5} N (repulsive)

(c) 16×10^{-5} N (attractive)

(d) 16×10^{-5} N (repulsive)

Ans : SQP 2001

Distance between conductors,

$$d = 0.5\,\text{m}$$

Current in first conductor,

$$I_1 = 5\,\text{A}$$

and current in second conductor,

$$I_2 = 8\,\text{A}$$

Force experienced by each conductor due to currents,

$$F = \frac{\mu_0 I_1 I_2 l}{2\pi d}$$

$$= \frac{(4\pi \times 10^{-7}) \times 5 \times 8 \times 1}{2\pi \times 0.5}$$

$$= 1.6 \times 10^{-5}\,\text{N}$$

(where, $\mu_0 =$ Absolute permeability of free space equal to $4\pi \times 10^{-7}\,\text{Wb A}^{-1}\,\text{m}^{-1}$)

Since, when current in both the conductors flows in the same direction, therefore force between them will be attractive. Thus (a) is correct option.

40. A current-carrying loop is placed in a uniform magnetic field. The torque acting on it does not depend upon

(a) area of loop.

(b) shape of loop.

(c) no. of turns in loop.

(d) strength of current and magnetic field.

Ans : Main 2004

Torque acting on a current-carrying loop in a uniform magnetic field,

$$\tau = nIAB\sin\theta$$

Therefore, torque does not depend on the shape of loop.

(where $I =$ current, $A =$ area of loop, $B =$ magnetic field, $n =$ no. of turns in loop and $\theta =$ Angle between magnetic field and normal to the surface of coil)

Thus (b) is correct option.

41. A circular loop of area $0.01\,\text{m}^2$ carrying a current of 10 A, is held perpendicular to a magnetic field of intensity 0.1 T. The torque acting on the loop is

(a) zero (b) 0.01 N-m

(c) 0.1 N-m (d) 0.8 N-m

Ans : Main 2014

Given

Area of circular loop, $A = 0.01\,\text{m}^2$

Current in the loop, $I = 10\,\text{A}$

Angle between the magnetic field and normal to the surface of coil

$$\theta = 0^\circ$$

Magnetic field, $B = 0.1\,\text{T}$

torque acting on the loop,

$$\tau = IAB\sin\theta$$

$$= 10 \times 0.01 \times 0.1 \times \sin 0^\circ$$

$$= 0$$

Thus (a) is correct option.

42. On connecting a battery to the two corners of a diagonal of a square conductor frame of side a, the magnitude of magnetic field at the centre will be

(a) zero (b) $\frac{\mu_0}{\pi a}$

(c) $\frac{\mu_0}{2\pi a}$ (d) $\frac{2\mu_0}{\pi a}$

Ans : Comp 2015, 2011

When a battery is connected two corners of a diagonal of a square conductor frame, then the conductor frame can be taken as two sets of parallel wires carrying currents in the same direction.

The magnetic field at the centre due to two parallel wires carrying currents in the same direction will be equal in magnitude, but opposite in directions. Therefore, magnitude of the magnetic field at the centre will be zero.

Thus (a) is correct option.

43. Two thin, long, parallel wires, separated by a distance d carry a current of (i) A in the same direction. They will

(a) attract each other with a force of $\mu_0 i^2/(2\pi d)$

(b) repel each other with a force of $\mu_0 i^2/(2\pi d)$

(c) attract each other with a force of $\mu_0 i^2/(2\pi d^2)$

(d) repel each other with a force of $\mu_0 i^2/(2\pi d^2)$

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Ans : **SQP 2018**

Given,

Distance between wires $= d$

and current in each wire $= i$ A

Force on each wire due to current,

$$F = \frac{\mu_0 i^2}{2\pi d}$$

Since, current flows in both the parallel wires in the same direction, therefore they attract each other with a force of $\mu_0 i^2/2\pi d$.

Thus (a) is correct option.

44. A proton moving with a velocity $2.5 \times 10^7\,\text{ms}^{-1}$, enters a magnetic field of intensity 2.5 T at an angle 30° with the magnetic field. The force on the proton is

(a) 3×10^{-12} N (b) 5×10^{-12} N

(c) 6×10^{-12} N (d) 9×10^{-12} N

Ans : **Main 2008**

Given,

Velocity of proton, $v = 2.5 \times 10^7\,\text{ms}^{-1}$

Intensity of magnetic field, $B = 2.5$ T

and angle between magnetic field and direction of motion of proton,

$$\theta = 30^\circ$$

Force acting on the charged particle in magnetic field,

$$F = q\upsilon B \sin\theta$$

Where, $q =$ charge of proton equal to 1.6×10^{-19} C

$$= (1.6 \times 10^{-19}) \times (2.5 \times 10^7) \times 2.5 \times \sin 30^\circ$$

$$= (10 \times 10^{-12}) \times 0.5$$

$$= 5 \times 10^{-12}\,\text{N}$$

Thus (b) is correct option.

45. The radius of a circular path in which an electron will move, when subjected to a perpendicular uniform magnetic field (B), is

(a) $\frac{me}{B}$ (b) $\frac{mB}{e}$

(c) $\frac{Be}{m\upsilon}$ (d) $\frac{m\upsilon}{Be}$

Ans : **Main 2013, 2007**

Centrifugal force on the electron,

$$F_1 = m\omega^2 r$$

$$= m\left(\frac{\upsilon}{r}\right)^2 r = \frac{m\upsilon^2}{r}$$

And magnetic force on the moving charge in the magnetic field,

$$F_2 = Bev$$

Equating these two forces,

$$\frac{m\upsilon^2}{r} = Bev$$

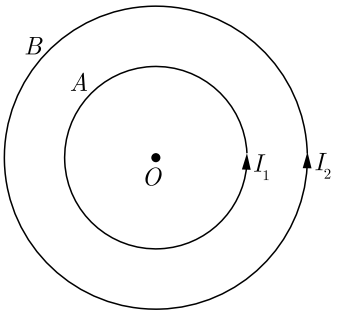
$$r = \frac{mv}{Be}$$

where, $e =$ charge on electron

and $r =$ Radius of circular path

Thus (d) is correct option.

46. A and B are two concentric circular conductors of centre O and carrying currents I_1 and I_2 as shown in the adjacent figure. If ratio of their radii is 1 : 2 and ratio of the magnetic flux densities at O due to A and B is 1 : 3, then the value of I_1/I_2 is



(a) $\frac{1}{6}$ (b) $\frac{1}{4}$

(c) $\frac{1}{3}$ (d) $\frac{1}{2}$

Ans : **Main 2014**

Given,

Radius of conductor A, $r_1 = r$

Radius of conductor B, $r_2 = 2r$

Magnetic flux density due to conductor A,

$$B_1 = B$$

and magnetic flux density due to conductor B,

$$B_2 = 3B$$

Magnitude of magnetic flux density at the centre of a current-carrying circular conductor,

$$B = \frac{\mu_0 I}{2r} \propto \frac{I}{r}$$

Therefore, $\frac{B_1}{B_2} = \frac{I_1}{I_2} \times \frac{r_2}{r_1}$

$$\frac{1}{3} = \frac{I_1}{I_2} \times \frac{2}{1}$$

$$\frac{I_1}{I_2} = \frac{1}{6}$$

Thus (a) is correct option.

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(c) Assertion is correct but Reason is incorrect.

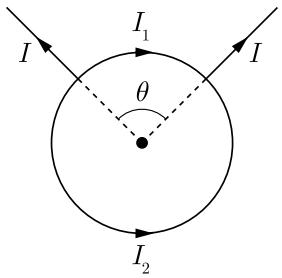
(d) Assertion is incorrect but Reason is correct.

Ans : **Main 2017**

In the absence of the electric current, the free electrons in a conductor are in a state of random motion, like molecular in a gas. Their average velocity is zero. i.e. they do not have any net velocity in a direction. As a result, there is no net magnetic force on the free electrons in the magnetic field. On passing the current, the free electrons acquire drift velocity in a definite direction, hence magnetic force acts on them, unless the field has no perpendicular component.

Thus (b) is correct option.

61. **Assertion :** The magnetic field at the centre of the circular coil in the following figure due to the currents I_1 and I_2 is zero.



Reason : $I_1 = I_2$ implies that the fields due to the current I_1 and I_2 will be balanced.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **SQP 2011**

$$\frac{I_1}{I_2} = \frac{2\pi - \theta}{\theta}$$

$$I_1\theta = I_2(2\pi - \theta) \qquad \text{...(i)}$$

$$B_1 = \frac{\theta}{2\pi} \cdot \frac{\mu_0 I_1}{2R}$$

and $$B_2 = \frac{2\pi - \theta}{2\pi} \cdot \frac{\mu_0 I_2}{2R}$$

Using (i), we get

$$B_1 = B_2$$

Thus (d) is correct option.

ONE MARK QUESTIONS

62. Write Biot-Savart's law in vector form.

Ans : **Main 2020**

$$dB = \frac{\mu_0}{4\pi} \cdot \frac{I\, dl \sin\theta}{r^2}$$

63. What will be the path of a charged particle moving along the direction of a uniform magnetic field ?

Ans : **Main 2019, 2011**

The path of particle will remain unchanged (since magnetic force $F_m = qvB\sin\theta = 0$).

64. What is the nature of magnetic field in a moving coil galvanometer?

Ans : **SQP 2017**

The nature of magnetic field in a moving coil galvanometer is radial.

65. Why are the pole pieces of a horseshoe magnet in a moving coil galvanometer made cylindrical in shape?

Ans : **Main 2024**

For increasing the strength of the magnetic field, the pie pieces of a horseshoe magnet in a moving coil galvanometer are made cylindrical in shape.

66. Under what condition is the force acting on a charge moving through a uniform magnetic field is minimum?

Ans : **SQP 2013**

$F_m = qvB\sin\theta$; for minimum force $\sin\theta = 0$, i.e., force is minimum when charged particle move parallel or anti-parallel to the field.

67. State Ampere's circuital law.

Ans : **Main 2005**

The line integral of the magnetic field $\vec{B}$ around any closed loop is equal to μ_0 times the total current passing through the loop. i.e. $\oint \vec{B} \cdot d\vec{l} = \mu_0 I$

where, I = total current inside the closed path.

68. Is the steady electric current the only source of magnetic field? Justify your answer.

Ans : **Main 2020**

Yes, the net magnetic force acting on a wire carrying a steady (constant) electric current I in an external magnetic field B and is given by

$$F = IdlB$$

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50. A current passing through a circular coil of two turns produces a magnetic field of 8 T at its centre. The coil is then rewound, so as to have four turns and current is passed through it is doubled. Now magnetic field at the centre of the coil will be

(a) 64 T (b) 32 T

(c) 16 T (d) 8 T

Ans : **Comp 2005, 2009**

Given,

Initial number of turns, $n_1 = 2$

Initial magnetic field at centre, $B_1 = 8\text{ T}$

Final no. of turns in coil, $n_2 = 4$

Final current in the coil, $I_2 = 2I_1$

(where, I_1 is the initial current)

Since, circumference of two coil is equal to circumference of four turn coil,

Therefore, $2 \times 2\pi r_1 = 4 \times 2\pi r_2$

$$r_1 = 2r_2$$

Magnetic field at the centre of a current-carrying circular coil,

$$B = \frac{\mu_0 nI}{2r} \propto \frac{nI}{r}$$

Therefore, $$\frac{B_1}{B_2} = \frac{n_1}{n_2} \times \frac{I_1}{I_2} \times \frac{r_2}{r_1}$$

$$= \frac{2}{4} \times \frac{I_1}{2I_1} \times \frac{r_2}{2r_2} = \frac{1}{8}$$

$$B_2 = 8B_1 = 8 \times 8 = 64\text{ T}$$

Where, B_2 = final magnetic field at centre of coil

Thus (a) is correct option.

51. Two circular coils of radii 15 cm and 30 cm are made of similar wires and have same number of turns. If they are connected in parallel, then ratio of their magnetic inductions at the centre of the coils is

(a) 1 : 2 (b) 2 : 1

(c) 1 : 4 (d) 4 : 1

Ans : **SQP 2014**

Given,

Radius of first coil, $r_1 = 15\text{ cm} = 0.15\text{ m}$

Radius of second coil, $r_2 = 30\text{ cm} = 0.3\text{ m}$

and no. of turns in each coil = n

resistance of coil,

$$R = 2\pi rn \times \rho$$

where, ρ = resistance per unit length

Therefore, current in coil,

$$I = \frac{V}{R} = \frac{V}{2\pi rn\rho}$$

We also know that magnetic induction at the centre of a current-carrying circular coil,

$$B = \frac{\mu_0 nI}{2r}$$

$$= \frac{\mu_0 n}{2r} \times \frac{V}{2\pi rn\rho}$$

$$= \frac{\mu_0}{4\pi r^2} \times \frac{V}{\rho}$$

Since, both the coils are connected in parallel, therefore potential difference V across both the coils is same and resistance per unit length of the wires will also be same, because they are made of similar wires.

Thus, $B \propto \frac{1}{r^2}$

Therefore, $$\frac{B_1}{B_2} = \left(\frac{r_2}{r_1}\right)^2 = \left(\frac{0.3}{0.15}\right)^2 = \frac{4}{1}$$

$$B_1 : B_2 = 4 : 1$$

Thus (d) is correct option.

52. A particle of mass m and charge q moves with a constant velocity υ along the positive x-direction. It enters a region containing a uniform magnetic field B directed along the negative z-direction, extending from $x = a$ to $x = b$. The minimum value of υ required, so that the particle can just enter the region of $x > b$ is

(a) $\frac{qbB}{m}$ (b) $\frac{qaB}{m}$

(c) $\frac{q(b-a)B}{m}$ (d) $\frac{q(b+a)B}{2m}$

Ans : **Main 2012**

Given,

Mass of particle $= m$

Charge on particle $= q$

Velocity of particle $= v$

...(directed along positive x-direction)

Uniform magnetic field $= B$

...(directed along negative z-direction, extending from $x = a$ to $x = b$)

When a charged particle enters in a uniform magnetic field, directed vertically upwards, then the particle will move in a circular path and radius of this circular path,

$$r = b - a = \frac{m\upsilon}{qB}$$

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Therefore, particle can not enter the region $x > b$. And if the particle is to enter the region $x > b$,

Then, $r > (b - a)$

$$\frac{mv}{Bq} > (b - a)$$

$$v > \frac{q(b-a)B}{m}$$

where, v = minimum velocity of particle

Thus (c) is correct option.

53. Two concentric coils each of radius equal to 2π cm are placed at right angles to each other. If 3 A and 4 A are the currents flowing in each coil respectively, then resultant magnetic field in Wb m^{-2} at the centre of the coils will be $(\mu_0 = 4\pi \times 10^{-7}\ \text{Wb A}^{-1}\text{m}^{-1})$

(a) 10^{-5} (b) 5×10^{-5}

(c) 7×10^{-5} (d) 12×10^{-5}

Ans : Main 2009, 2001

Given,

Radius of each circular loop,

$$r = 2\pi \text{ cm} = 2\pi \times 10^{-2} \text{ m}$$

Current in first loop, $i_1 = 3$ A

Current in second loop, $i_2 = 4$ A

Magnetic field at the centre of first circular coil due to its current,

$$B_1 = \frac{\mu_0 i_1}{2r} = \frac{(4\pi \times 10^{-7}) \times 3}{2 \times (2\pi \times 10^{-2})} = 3 \times 10^{-5}\ \text{T}$$

Similarly, magnetic field at the centre of second circular coil due to its current,

$$B_2 = \frac{\mu_0 i_2}{2r} = \frac{(4\pi \times 10^{-7}) \times 4}{2 \times (2\pi \times 10^{-2})} = 4 \times 10^{-5}\ \text{T}$$

Since, both the coils are perpendicular to each other, therefore directions of their magnetic fields will also be perpendicular to each other. Thus, resultant magnetic field at the centre of the coils,

$$B = \sqrt{(B_1)^2 + (B_2)^2} = \sqrt{(3 \times 10^{-5})^2 + (4 \times 10^{-5})^2} = 5 \times 10^{-5}\ \text{Wb} - \text{m}^{-2}$$

Thus (b) is correct option.

54. Current flowing through a long solenoid is varied, then magnetic flux density of the magnetic field inside it varies

(a) inversely with I

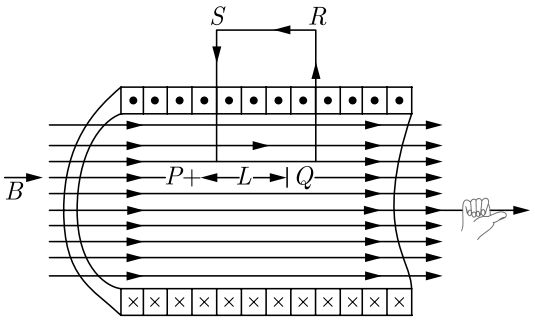
(b) inversely with I^2

(c) directly with I

(d) directly with I^2

Ans : SQP 2018, 2011

Let a rectangular amperian loop $PQRS$ is taken in a solenoid. Now, applying Ampere's circuital law in this loop



$$\oint_{PQRS} \vec{B} \cdot d\vec{l} = \int_P^Q \vec{B} \cdot d\vec{l} + \int_Q^R \vec{B} \cdot d\vec{l} + \int_R^S \vec{B} \cdot d\vec{l} + \int_S^P \vec{B} \cdot d\vec{l} = \mu_0 nLI \quad ...(1)$$

On remaining three sides i.e. RQ, SR and PQ, $\vec{B} \cdot d\vec{l}$ is zero as $\vec{B}$ is either zero or perpendicular to $d\vec{l}$. Thus,

$$\int_P^Q \vec{B} \cdot d\vec{l} = BL$$

Hence, Eq. (1) becomes

$$BL = \mu_0 nLI$$

$$B = \mu_0 nI \text{ or } B \propto I$$

Thus (c) is correct option.

ASSERTION AND REASON

55. **Assertion :** To convert a galvanometer into an ammeter a small resistance is connected in parallel with it.

Reason : The small resistance increases the combined resistance of the combination.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

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Ans : SQP 2015

An ammeter should have a low resistance which we get when we connect low resistance in parallel with galvanometer. Thus (c) is correct option.

56. **Assertion :** In electric circuits, wires carrying currents in opposite directions are often twisted together.

Reason : If the wires are not twisted together, the combination of the wires forms a current loop, the magnetic field generated by the loop might affect adjacent circuits or components.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : Main 2017

If the wires are twisted together, they can be formed as a single wire carrying currents in opposite directions. In this pattern, in wires no magnetic field is induced which does not affect adjacent circuits.

Thus (a) is correct option.

57. **Assertion :** A charge, whether stationary or in motion produces a magnetic field around it.

Reason : Moving charges produce only electric field in the surrounding space.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : SQP 2007

A charge, whether stationary or in motion, produces an electric field around it. If it is in motion, then in addition to the electric field, it also produces a magnetic field, because moving charges produces magnetic field in the surrounding space. Thus (d) is correct option.

58. **Assertion :** If the current in a solenoid is reversed in direction while keeping the same magnitude, the magnetic field energy stored in the solenoid decreases.

Reason : Magnetic field energy density is proportional to square of current.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : Main 2018, 2016

Reversing the direction of the current reverses the direction of the magnetic field. However, it has no effect on the magnetic field energy density, which is proportional to the square of the magnitude of the magnetic field.

Thus (d) is correct option.

59. **Assertion :** The magnetic field produced by a current carrying solenoid is independent of its length and cross-sectional area.

Reason : The magnetic field inside the solenoid is uniform.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : Comp 2025

Magnetic field inside the solenoid at point P is given by,

$$B = \frac{\mu_0}{4\pi}(2\pi ni)\,[\sin\alpha + \sin\beta]$$

where n = no. of turns per unit length $= N/\ell$

Thus it is clear that magnetic field is independent of length and cross sectional area.

Also the magnetic field with in the solenoid in uniform and parallel to the axis of the solenoid.

Thus (b) is correct option.

60. **Assertion :** Free electrons always keep on moving in a conductor even then no magnetic force act on them in magnetic field unless a current is passed through it.

Reason : The average velocity of free electron is zero.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

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47. The magnetic field at the centre of a circular loop of area A is B. The magnetic moment of the loop will be

(a) $\frac{BA^2}{\mu_0\pi}$ (b) $\frac{BA^{3/2}}{\mu_0}$

(c) $\frac{BA^{3/2}}{\mu_0\pi}$ (d) $\frac{2BA^{3/2}}{\mu_0\sqrt{\pi}}$

Ans : SQP 2011, 2008

Given,

$$\text{Area of circular loop} = A$$

$$\text{Magnetic field at the centre of loop} = B$$

Magnetic moment, $M = i \cdot A$ ...(1)

Since, $B = \frac{\mu_0 i}{2R}$

$$i = \frac{2BR}{\mu_0} \quad ...(2)$$

$$A = \pi R^2 \text{ (for circular loop)} \quad ...(3)$$

Substituting the value of Eq. (3) and (2) in Eq. (1), we get,

$$M = \frac{2BR}{\mu_0} \times A$$

$$= \frac{2BR \times A}{\mu_0} = \frac{2BRA}{\mu_0} \times \frac{\sqrt{A}}{\sqrt{A}}$$

$$= \frac{2BRA^{3/2}}{\mu_0\sqrt{\pi R^2}} \quad \text{[From Eq. (3)]}$$

$$= \frac{2BA^{3/2}}{\mu_0\sqrt{\pi}}$$

Thus (d) is correct option.

48. A toroid has a core of inner radius 20 cm and outer radius 22 cm around which 4200 turns of a wire are wound. If current in the wire is 10 A, then magnetic field inside the core of toroid is

(a) 0.01 T (b) 0.02 T

(c) 0.04 T (d) 0.08 T

Ans : SP 2024

Given,

Inner radius, $r_1 = 20\,\text{cm} = 0.2\,\text{m}$

Outer radius, $r_2 = 22\,\text{cm} = 0.22\,\text{m}$

No. of turns, $N = 4200$

Current in toroid, $r = \frac{r_1 + r_2}{2}$

$$= \frac{0.2 + 0.22}{2} = 0.21\,\text{m}$$

Therefore, total length of toroid,

$$L = \text{circumference of toroid}$$

$$= 2\pi r = 2\pi \times 0.21 = 0.42\pi$$

and number of turns per unit length of toroid,

$$n = \frac{N}{L} = \frac{4200}{0.42\pi} = \frac{10000}{\pi}$$

We also know that magnetic field inside the core of toroid,

$$B = \mu_0 nI$$

$$= (4\pi \times 10^{-7}) \times \frac{10000}{\pi} \times 10$$

$$= 0.04\,\text{T}$$

(where $\mu_0 =$ Absolute permeability of free space equal to $4\pi \times 10^{-7}\,\text{Wb A}^{-1}\,\text{m}^{-1}$)

Thus (c) is correct option.

49. A charged particle of mass m and charge q travels on a circular path of radius r that is perpendicular to the magnetic field B. The time-taken by the particle to complete one revolution is

(a) $\frac{2\pi m}{qB}$ (b) $\frac{2\pi qB}{m}$

(c) $\frac{2\pi mq}{B}$ (d) $\frac{2\pi q^2 B}{m}$

Ans : SQP 2007

Given,

$$\text{Mass of particle} = m$$

$$\text{Charge on particle} = q$$

$$\text{Radius of circular path} = r$$

and $$\text{Magnetic field} = B$$

magnetic force on the charged particle in magnetic field,

$$F_1 = Bqv$$

and centrifugal force on the charged particle moving in circular path,

$$F_2 = \frac{mv^2}{r}$$

Since charged particle is moving in circular path,

Therefore, $F_1 = F_2$

$$Bq\upsilon = \frac{mv^2}{r}$$

$$v = \frac{Bqr}{m}$$

We also know that time-taken by the particle to complete one revolution

$$= \frac{\text{Circumference}}{\text{Velocity}}$$

$$= \frac{2\pi r}{v} = \frac{2\pi r}{\frac{Bqr}{m}}$$

$$= \frac{2\pi m}{Bq}$$

Thus (a) is correct option.

NODIA

69. State Biot-Savart law in vector form expressing the magnetic field due to an element $\vec{dl}$ carrying current I at a distance $\vec{r}$ from the element.

Ans : **SQP 2014**

It states that for a small current element dl the magnetic field at a distance r is given by

$$\overrightarrow{dB} = \frac{\mu_0}{4\pi}\frac{I(\vec{dl}\times\hat{r})}{r^2}$$

70. Define ampere in terms of force between two current carrying conductors.

Ans : **Main 2016**

One ampere is that value of steady current which on flowing in each of two parallel infinitely long conductors of negligible cross-section placed in vacuum at a distance of 1 m from each other, produces a force of 2×10^{-7} newton per metre between them.

71. Write the expression, in a vector form, for the Lorentz magnetic force $\vec{F}$ due to a charge moving with velocity $\vec{v}$ in a magnetic field $\vec{B}$. What is the direction of the magnetic force ?

Ans : **SQP 2021, 2012**

Force, $\vec{F} = q(\vec{v}\times\vec{B})$

Obviously, the force on charged particle is perpendicular to both velocity $\vec{v}$ and magnetic field $\vec{B}$.

72. Must every magnetic field configuration have a north pole and a south pole? Explain with example.

Ans : **Main 2011**

No, because the concept of magnetic poles is fictitious; the fundamental quantity in magnetism is magnetic moment. Therefore, a toroid (endless solenoid) and a straight conductor do not have north and south poles.

73. When would a moving charged particle travel undeviated in a uniform magnetic field?

Ans : **Main SQP 2018**

When a charged particle is moving parallel to the magnetic field force exerted by the field on the particle is, $F = qvB\sin\theta = 0$. Hence, the path of charged particle, remains unchanged i.e. straight line.

74. Write the expression for the Lorentz force $\vec{F}$ in vector form.

Ans : **Main 2016**

In vector form, expression for Lorentz force can be given as

$$\vec{F} = \vec{F}_e + \vec{F}_m = q\vec{E} + q(\vec{v}\times\vec{B})$$
$$\vec{F} = q(\vec{E} + \vec{v}\times\vec{B})$$

75. Which of the two, an ammeter or a voltmeter has a greater resistance?

Ans : **Main SQP 2018**

Resistance of voltmeter is greater than ammeter, because in voltmeter, galvanometer is connected with a high resistance in series, while in ammeter small shunt resistance connected in parallel with galvanometer.

76. State two factors on which the sensitivity of a moving coil galvanometer depends.

Ans : **Main 2025**

The current sensitivity and voltage sensitivity of the galvanometer depend on the number of turns of coil, magnetic field $\vec{B}$, area A of the coil and torsion constant k of the spring or suspension wire.

77. What is the purpose of concave pole pieces in a moving coil galvanometer?

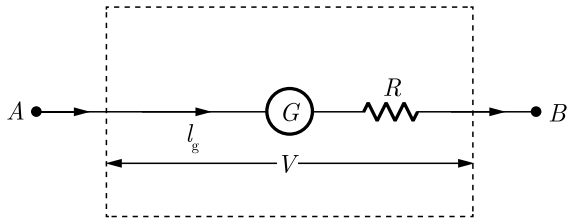
Ans : **Main 2001**

The purpose of concave pole pieces in a moving coil galvanometer is to ensure that the plane of the coil is always parallel to the magnetic field, such that $\theta = 90^\circ$ and $\tau = NIBA$ where, symbols have their usual meanings.

78. How can a moving coil galvanometer be converted into a voltmeter?

Ans : **Main 2020, 2018**

A moving coil galvanometer can be converted into a voltmeter by using a high resistance is connected in series with the galvanometer.



79. Using the concept of force between two infinitely long parallel current carrying conductors define one ampere of current.

Ans : **SQP 2020**

One ampere is that value of current which flows through two straight, parallel infinitely long current carrying conductors placed in air or vacuum at a distance of 1 m and they experience a force of attractive or repulsive nature of magnitude 2×10^{-7} N/m on their unit length.

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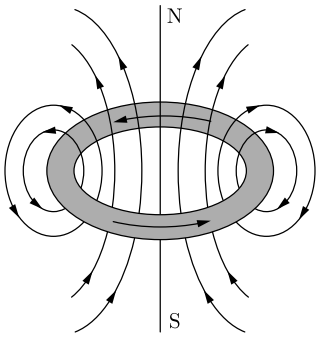
80. Draw the magnetic field lines due to a current carrying loop.

Ans : **Comp 2021**

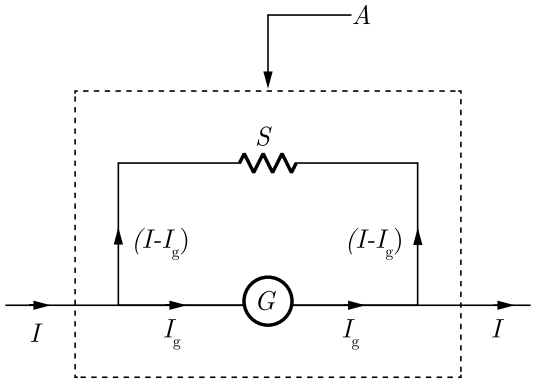
Magnetic field lines due to a current carrying loop are given by



81. State how a moving coil galvanometer can be converted into an ammeter.

Ans : **Main 2016**

A moving coil galvanometer can be converted into an ammeter by using a low resistance wire in parallel with it.



82. Write an expression for force per unit length between two long current carrying wires, kept parallel to each other, in vacuum and hence define an ampere, the SI unit of current.

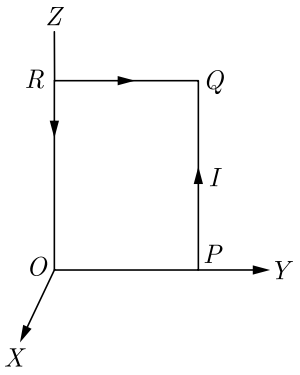
Ans : **Main 2020**

Magnetic force per unit length between two straight parallel current carrying conductors is given by

$$f = \frac{F}{l} = \frac{\mu_0}{4\pi} \cdot \frac{2I_1 I_2}{r} = \frac{\mu_0 I_1 I_2}{2\pi r}$$

where, I_1 and I_2 are current in the wires, r is the distance between wires and l is the length of each conductor.

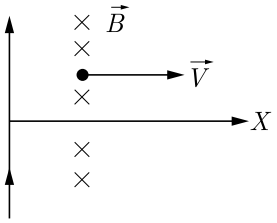
83. A square coil $OPQR$ of side a carrying a current I, is placed in the Y-Z plane as shown here. Find the magnetic moment associated with this coil.



Ans : **Main 2015, 2010**

The magnetic moment associated with the coil, is $\vec{\mu}_m = Ia^2\hat{i}$

84. A long straight wire carries a steady current I along the positive Y-axis in a coordinate system. A particle of charge $+Q$ is moving with a velocity $\vec{v}$ along the X-axis. In which direction will the particle experience a force ?



Ans : **Main 2013**

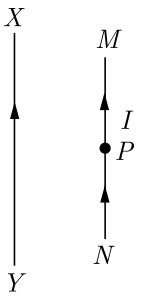
From relation, $\vec{F} = qvB[\hat{i} \times (-\hat{k})]$

$= + qvB(\hat{j})$

Magnetic force $\vec{F}$ along $+Y$ axis.

85. Figure shows a point P near a long conductor XY carrying a current I.

MN is a short current conductor, kept at the point P, parallel to the conductor XY. What is the direction of magnetic flux density B at the point P due to the current flowing through XY ?



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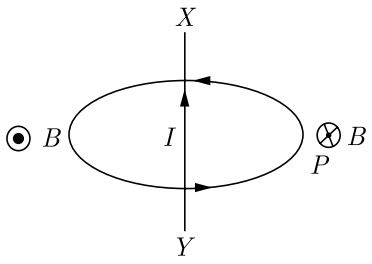
Ans : **Main 2012**

According to Biot-Savart's law, we can say that the direction of magnetic flux density at the point P due to the current flowing through the conductor XY is perpendicular to the plane of the paper directed into the page, as shown in the diagram.



TWO MARKS QUESTIONS

86. Briefly explain various ways to increase the strength of magnetic field produced by a given solenoid.

Ans : **SQP 2003**

The strength of the magnetic field produced by the solenoid can be increased.

(i) By placing soft iron inside the solenoid.

(ii) By increasing the number of turns of the coil.

(iii) By increasing the current flowing through the solenoid.

87. Write any two important points of similarities between Coulomb's law for the electrostatic field and Biot-Savart's law for the electrostatic field and Biot-Savart's law for the magnetic field.

Ans : **SQP 2025**

Similarities of electrostatic field and magnetic field:

1. Follows the principle of superposition.
2. Depends inversely on the square of distance from source to the point of interest.

88. In a certain region of space, electric field $\vec{E}$ and magnetic field $\vec{B}$ are perpendicular to each other. An electron enters in the region perpendicular to the directions of both $\vec{B}$ and $\vec{E}$ and moves undeflected. Find the velocity of the electron.

Ans : **SQP 2010**

Net force on electron moving in the combined electric field $\vec{E}$ and magnetic field $\vec{B}$ is

$$\vec{F} = -e[\vec{E} + \vec{v} \times \vec{B}]$$

Since electron moves undeflected then $\vec{F} = 0$

$$\vec{E} + \vec{v} \times \vec{B} = 0$$

$$|\vec{E}| = |\vec{v}| \times |\vec{B}|$$

$$|\vec{v}| = \frac{|\vec{E}|}{|\vec{B}|}$$

89. A moving charged particle q travelling along the positive X-axis enters a uniform magnetic field $\vec{B}$. When will the force acting on q be maximum?

Ans : **Main 2018**

Force experienced by a moving charged particle is given by $F = qvB\sin\theta$

where, θ is the angle between $\vec{v}$ and $\vec{B}$.

If $\theta = 90^\circ$, then $\sin\theta = 1$ (maximum)

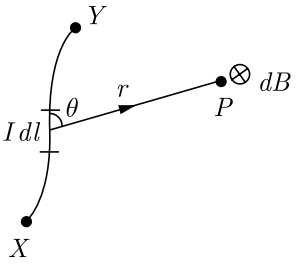
$$F_{max} = qvB \text{ (maximum)}$$

Hence, if charged particle is moving perpendicular to the direction of magnetic field $\vec{B}$, it experiences a maximum force which acts perpendicular to the direction of $\vec{B}$ and $\vec{v}$.

90. State Biot-Savart's law.

Ans : **Main 2014, 2005, 2001**

According to this law, the magnetic field due to the small current carrying element of any near by point P is given by



$$d\vec{B} = \frac{\mu_0}{4\pi} \cdot \frac{Idl \times \vec{r}}{|r|^3}$$

$$dB = \frac{\mu_0}{4\pi} \cdot \frac{Idl\sin\theta}{r^2}$$

91. Write the expression for Lorentz magnetic force on a particle of charge q moving with velocity $\vec{v}$ in a magnetic field $\vec{B}$. Show that no work is done by this force on the charged particle.

Ans : **SQP 2019**

Magnetic Lorentz force,

$$\vec{F}_m = q(\vec{v} \times \vec{B})$$

$$\vec{F} \perp \vec{v}$$

Force is perpendicular to displacement made by charge particle.

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Hence, $W = Fd\cos 90^\circ = 0$

[Since, F and displacement are perpendicular to each other]

$$W = 0$$

No work is done by magnetic Lorentz force on the charge particle.

92. Define one tesla using the expression for the magnetic force acting on a particle of charge q moving with velocity $\vec{v}$ in a magnetic field $\vec{B}$.

Ans : **Main 2013, 2006**

One tesla is the magnetic field in which a charge of 1C moving with a velocity of 1ms^{-1}, normal to the magnetic field, experiences a force of 1 N.

$$B = \frac{F}{qv\sin\theta}$$

If $F = 1\,\text{N}$

$q = 1\,\text{C}$

$v = 1\,\text{ms}^{-1}$ and $\theta = 90^\circ$

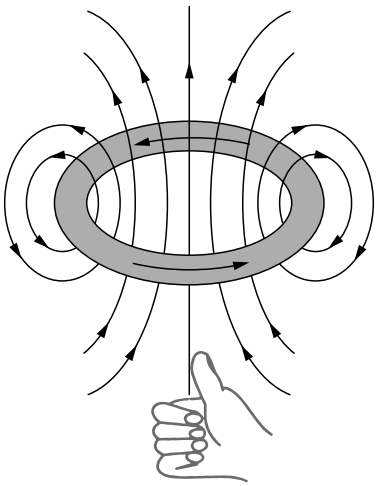
Then, SI unit of $B = \dfrac{1\,\text{N}}{1\,\text{C}\cdot 1\,\text{ms}^{-1}\cdot\sin 90^\circ}$

$= 1\,\text{NA}^{-1}\text{m}^{-1} = 1$ tesla

93. Write the expression for the magnitude of the magnetic field at the centre of a circular loop of radius r carrying a steady current I. Draw the field lines due to the current loop.

Ans : **SQP 2011**

Magnetic field at the centre of a circular loop is given by the field lines are as shown :



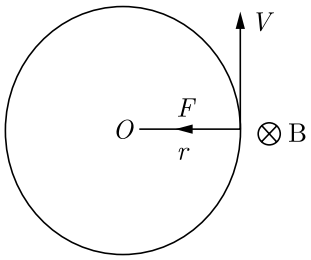
94. Show that the radius of a charged particle entering perpendicularly in a magnetic field is directly proportional to its momentum.

Ans : **Main 2004**

When a charged particle enters in a uniform magnetic field perpendicularly, central force acts on the particle which provides centripetal force for the circular motion of the particle.

Situation is shown in figure

Centripetal force, $F = \dfrac{mv^2}{r}$



As magnetic force will provide the necessary centripetal force to the charged particle.

$$\frac{mv^2}{r} = qvB$$

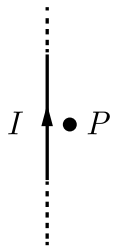
$$\frac{mv}{r} = qB$$

$$p = mv = rqB$$

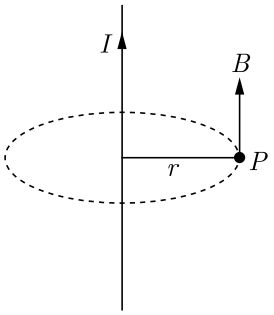
$$r = \frac{p}{qB} \Rightarrow r \propto p$$

Where, $p = mv =$ momentum.

95. An electric current I flows through an infinitely long conductor as shown in the figure given alongside. Write an expression and direction for the magnetic field at point P.



Ans : **Main 2019**



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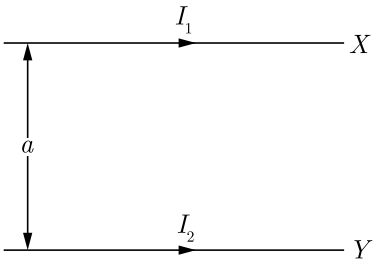
The magnitude of the magnetic field at a point P,

$$B = \frac{\mu_0 I}{2\pi r}$$

Its direction at point P is along the tangent to a circle of radius r centred on the conductor.

96. Figure below shows two infinitely long and thin current carrying conductors X and Y kept in vacuum, parallel to each other at a distance a.



(i) How much force per unit length act on the conductor Y due to the current flowing through X ? Write your answer in terms of $\left(\frac{\mu_0}{4\pi}\right)$, I_1, I_2 and a.

[Derivation of formula is not required]

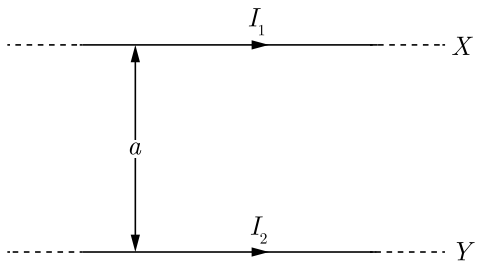
(ii) Define ampere in terms of force between two current carrying conductors.

Ans : **Main 2016, 2013, 2011,2008**

First, we have to find force between the wires by assuming that one of the wires is of finite length. Then, force is divided by length to find force per unit length.

(i) Let length of the wire Y be l.

Force on Y, $F_Y = \frac{\mu_0 I_1}{2\pi a}(I_2 l)$, towards X.



Force per unit length, $\frac{F_Y}{l} = \frac{\mu_0 I_1 I_2}{2\pi a}$

(ii) One ampere is that value of steady current which on flowing in each of two parallel infinitely long conductors of negligible cross-section placed in vacuum at a distance of 1 m from each other, produces a force of 2×10^{-7} newton per metre between them.

THREE MARKS QUESTIONS

97. State Ampere's circuital law expressing it in the integral form.

Ans : **SQP 2012**

Ampere's circuital law states that the line integral of magnetic field (B) around any closed path in vacuum is μ_0 times the net current (I) threading the area enclosed by the curve.

Mathematically, $\oint \vec{B} \cdot d\vec{l} = \mu_0 I$

Ampere's law is applicable only for an Amperian loop as the Gauss's law is used for Gaussian surface in electrostatics.

98. An electron moving through a field remains deflected. Is it possible that there is no magnetic field. Explain.

Ans : **SQP 2016**

Yes, it is possible. When a charge q moves with velocity $\vec{v}$ in a magnetic field $\vec{B}$ and $\vec{v}$ makes an angle θ with $\vec{B}$ then force on charge is given by,

$$\vec{F} = q\vec{v}B\sin\theta$$

If, $\theta = 0^\circ$ or 180°

Then, $F = 0$ (Since, $\sin 0^\circ$ or $\sin 180^\circ = 0$)

Hence, a charged particle moving parallel or anti-parallel to a magnetic field does not experience any force in the magnetic field.

99. Write an expression for the maximum kinetic energy acquired by charged particles accelerated by a cyclotron.

Ans : **Main 2025**

The ions will attain maximum velocity near the periphery of the dees. If v_0 is the maximum velocity acquired by the ions and r_0 is the radius of the dees, then

$$\frac{mv_0^2}{r_0} = qv_0 B$$

$$v_0 = \frac{qBr_0}{m}$$

The maximum kinetic energy of the ions will be,

$$K_0 = \frac{1}{2}mv_0^2 = \frac{1}{2}m\left(\frac{qBr_0}{m}\right)^2$$

$$K_0 = \frac{q^2B^2r_0^2}{2m}$$

100. When a charged particle moving with velocity $\vec{v}$ is subjected to magnetic field $\vec{B}$, the force acting on it is non-zero. Would the particle gain any energy?

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The following inferences can be drawn from the above discussion

(i) The conduction and displacement currents are individually discontinuous, but the currents together possess the property of continuity through any closed electric circuit.

(ii) The displacement current is precisely equal to the conduction current when the two present in different parts of the circuit.

(iii) The displacement current arises due to the rate of change of electric flux (or electric field) between the two plates of the capacitor.

(iv) Just as the conduction current is the displacement current is also the source of magnetic field.

122. Define current sensitivity and voltage sensitivity of a galvanometer. Increasing the current sensitivity may not necessarily increase the voltage sensitivity of a galvanometer. Justify.

Ans : **SQP 2012, 2011**

Current Sensitivity : The current sensitivity of a galvanometer is defined as the deflection product in the galvanometer when a unit charge flows through it.

If a current i produces a deflection ϕ in the galvanometer, then current sensitivity is

$$\frac{\phi}{i} = \frac{NAB}{C} \qquad ...(1)$$

Voltage Sensitivity : The voltage sensitivity of a galvanometer is defined as the deflection produced in the galvanometer when a unit voltage is applied across its coil. If a voltage V produces a defection ϕ in the galvanometer, then voltage sensitivity is

$$\frac{\phi}{V} = \frac{\phi}{iR} \qquad ...(2)$$

To explain that increasing the current sensitivity may not necessarily increase the voltage sensitivity let use assume that we double the number of turns i.e., $N \to 2N$, then

$$\text{Current sensitivity}, \frac{\phi}{i} \to 2\frac{\phi}{i} \qquad ...(3)$$

So, current sensitivity doubles. However, the resistance of the galvanometer is also likely to double, since it is proportional to the length of the wire. So,

$$N \to 2N \text{ and } R \to 2R$$

So, voltage sensitivity,

$$\frac{\phi}{V} \to \frac{\phi}{V}$$

$$\left[\text{As } \phi = \left(\frac{NAB}{C}\right)\frac{1}{R}\right] \text{ remains unchanged.}$$

123. Two identical circular coils, P and Q each of radius R, carrying currents 1 A and $\sqrt{3}$ A, respectively, are placed concentrically and perpendicular to each other lying in the XY and YZ planes. Find the magnitude and direction of the net magnetic field at the centre of the coils.

Ans : **Main 2010**

Field due to current in coil P is

$$\vec{B}_2 = \frac{\mu_0 I_1}{2R} \cdot k$$

(Assuming current to be anticlockwise as seen form positive Z-axis)

and that due to current in coil Q is

$$\vec{B}_2 = \frac{\mu_0 I_2}{2R}\hat{j}$$

(Assuming current to be anticlockwise as seen form positive X-axis)

Hence, net field, $\vec{B} = \vec{B}_1 + \vec{B}_2$

$$\vec{B} = \left(\frac{\mu_0 I_1}{2R}\right)\hat{k} + \left(\frac{\mu_0 I_2}{2R}\right)\hat{i}$$

Since, $I_1 = 2\text{ A}$ and $I_2 = \sqrt{3}\text{ A}$

$$= \left(\frac{\mu_0}{2R}\right)\hat{k} + \left(\frac{\sqrt{3}\mu_0}{2R}\right)\hat{i}$$

$$\vec{B} = \sqrt{\left(\frac{\mu_0}{2R}\right)^2 + \left(\frac{\sqrt{3}\mu_0}{2R}\right)^2}$$

$$= \frac{\mu_0}{2R}\sqrt{(1+3)} = \frac{\mu_0}{2R} \times 2$$

Hence, $\vec{B} = \frac{\mu_0}{R}$

The field is directed in XZ plane.

Let θ be the angle of $\vec{B}$ with positive X-axis.

Then, $\tan\theta = \left(\frac{\mu_0}{2R}\right) \Big/ \left(\frac{\sqrt{3}\mu_0}{2R}\right)$

or $\tan\theta = \frac{1}{\sqrt{3}}$

$\theta = 30^\circ$

Thus, $\vec{B}$ is directed in XZ plane making an angle of 30° with X-axis.

124. Obtain an expression for magnetic flux density B at the centre of a current carrying circular coil.

Ans : **SQP 2023**

Let there be a loop of radius a, carrying a current I and O be the centre of the loop, at which the field is required.

By Biot-Savart's law, the magnitude of the magnetic field at O due to a small element δl of the loop is

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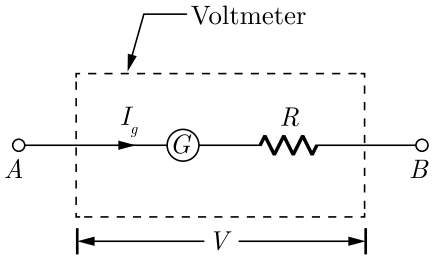
106. How is a moving coil galvanometer converted into a voltmeter? Explain giving the necessary circuit diagram and the required mathematical relation used.

Ans : SQP 2009

A galvanometer can be converted into a voltmeter by connecting a very high resistance R in series with it.

Let R is so chosen that current I_g gives full deflection in the galvanometer where I_g is the range of galvanometer.



Let galvanometer G of resistance R, range I_g is to be converted into voltmeter of range V (volt). Now,

$$V = I_g(G+R)$$
$$R+G = \frac{V}{I_g}$$
$$R = \frac{V}{I_g} - G$$

The appropriate scale need to be graduated to measure potential difference.

107. Write the expression for the force, $\vec{F}$ acting on a charged particle of charge q, moving with a velocity $\vec{v}$ in the presence of both electric field $\vec{E}$ and magnetic field $\vec{B}$. Obtain the condition under which the particle moves undeflected through the fields.

Ans : SQP 2014, 2010

Force $\vec{F}$ acting on a charge q moving with velocity v in the presence of both electric field $\vec{E}$ and magnetic field $\vec{B}$ is

$$\vec{F} = q\vec{E} + q(\vec{v} \times \vec{B})$$

Consider a region in which magnetic field, electric field and velocity of charge particle are perpendicular to each other.

To move charge particle undeflected the net force acting on the particle must be zero i.e., the electric force must be equal and opposite to the magnetic force.

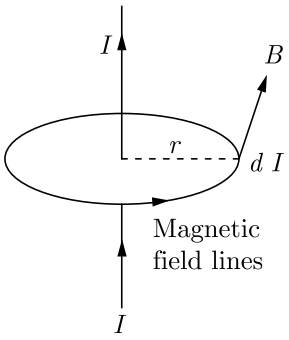
$$qE = qvB$$
$$v = \frac{E}{B}$$

The direction of electric and magnetic forces are in opposite direction. Their magnitudes are in such a way that they cancel out each other to give net force zero so that the charge particle does not deflect.

108. Using Ampere's circuital law, obtain an expression for magnetic flux density B at a point near an infinitely long and straight conductor, carrying a current I.

Ans : Main 2023

The line integral of the magnetic field B around any closed plane curve is equal to μ_0 times the net current (I) passing though the loop. It is expressed as $\oint B \cdot dl = \mu_0 I$



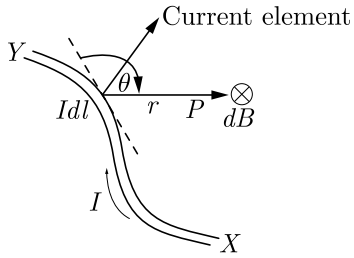
The magnitude of magnetic field of a long straight wire using Ampere's law. B and dl are in same direction.]

$$B = \frac{\mu_0 I}{2\pi r}$$

109. State Biot-Savart law and express this law in the vector form.

Ans : SQP 2024, 2014

According to Biot-Savart's law the magnitude of the magnetic field $\vec{d}B$ due to a small element of length dl of a current carrying wire at a point P, is proportional to the current I, the element length dl and is inversely proportional to the square of the distance r. It is also proportional to $\sin\theta$, where θ is the angle between $\vec{d}l$ and $\vec{r}$.



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Answer the following questions :

(i) Explain the reason of jumping of the ring when the switch is dosed in the circuit.

(ii) What will happen if the terminals of the battery are reversed and the switch is closed ? Explain.

(iii) Explain the two laws that help us to understand this phenomenon.

Ans : **Main 2023**

(i) By Lenz's law, the magnetic field produced by the induced eddy current in the ring opposes the changing magnetic field of the solenoid. Consequently, the two magnetic fields repel each other making the ring jump.

(ii) If the terminals of the battery are reversed, then current will be cut off. The cut keeps the ring from turning into a magnet, so ring will not jump.

(iii) The jumping ring is a demonstration of Faraday law of electromagnetic induction and also of Lenz's law.

Lenz's law states that an induced current in a closed conducting. Loop will appear in such a direction that it oppose the change that produces it.

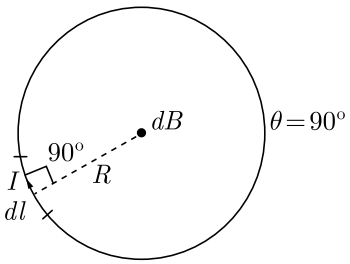
Faraday first law of electromagnets induction describes the induction of emf in a conductor and second law quantifies the emf produced in the conductor.

127. Obtain an expression for magnetic flux density B at the centre of a circular coil of radius R and having N turns, when a current I is flowing through it.

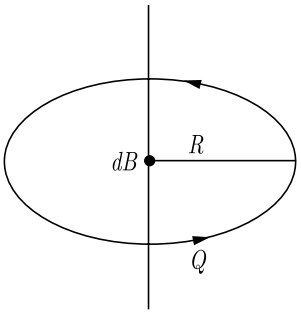
Ans : **Main 2009, 2001**

Take a small current element in the circular coil and find $\vec{B}$ due to it. After that integrate it for whole length of the loop.

Consider a small element dl on circular coil of radius R carrying current I.



By Biot-Savart's law, magnetic field at the centre due to element of coil.



$$dB = \frac{\mu_0}{4\pi} \cdot \frac{Idl\sin 90^\circ}{R^2}$$

$$dB = \frac{\mu_0}{4\pi} \cdot \frac{I}{R^2} dl$$

$$B = \oint \frac{\mu_0}{4\pi}\frac{I}{R^2} dl$$

$$= \frac{\mu_0}{4\pi}\frac{I}{R^2}\oint dl$$

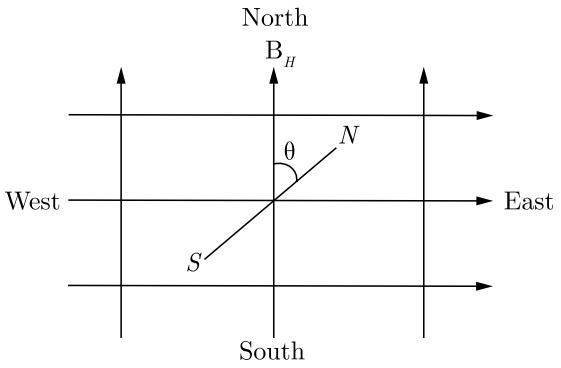
$$= \frac{\mu_0}{4\pi}\frac{I}{R^2} \times 2\pi R$$

$$B = \frac{\mu_0 I}{2R} \qquad \left[\oint dl = 2\pi R\right]$$

For N turns of coil,

$$B = \frac{\mu_0 NI}{2R}$$

128. A small magnetic needle NS having magnetic dipole moment $\vec{P}_m$ is kept in two uniform and perpendicular magnetic fields $\vec{B}_F$ and $\vec{B}_H$ as shown below.



(i) What is the effect of each of the magnetic field $\vec{B}_F$ and $\vec{B}_H$ on the needle ?

(ii) When the needle is in equilibrium, obtain an expression for angle θ made by the needle with $\vec{B}_H$ in terms of $\vec{B}_F$ and $\vec{B}_H$ only.

Ans : **Main 2010, 2009**

As the magnetic needle is placed in a two mutually perpendicular fields, both the fields will try to rotate the magnet in opposite directions.

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FOUR MARKS QUESTIONS

113. Give some points of similarities and differences between Biot-Savart law for the magnetic field and Coulomb's law for the electrostatic field.

Ans : SQP 2021

According to Coulomb's law, the electric field produced by a charged element is,

$$dE = \frac{1}{4\pi\varepsilon_0}\frac{dq}{r^2}$$

According to Biot-Savart law, the magnetic field produced by a current element $I\,dl$ is,

$$dB = \frac{\mu_0}{4\pi}\frac{I\,dl\sin\theta}{r^2}$$

On comparing the above two equations, we can note the following points:

Points of Similarity

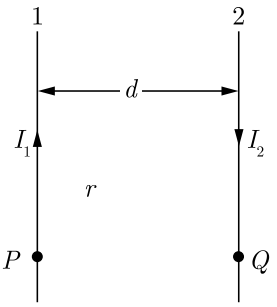
1. Both fields depend inversely on the square of the distance from the source.
2. Both are long range fields.
3. The principle of superposition is applicable to both fields.

Points of Difference

1. The magnetic field is produced by a vector source: the current element $I\vec{dl}$. The electrostatic field is produced by a scalar source: the electric charge dq.
2. The direction of the electrostatic field is along the displacement vector joining the source and the field point. The direction of the magnetic field is perpendicular to the plane containing the displacement vector $\vec{r}$ and the current element $I\vec{dl}$.
3. In Bio-Savart law, the magnitude of the magnetic field is proportional to the sine of the angle between the current element $I\vec{dl}$ and displacement vector $\vec{r}$ while there is no such angle dependence in the Coulomb's law for the electrostatic field.

114. Two very long conductors carrying currents I_1 and I_2 are separated by a distance d as shown in the figure. Give the expressions (do not derive) for the magnetic fields $\vec{B}_{12}$ and $\vec{B}_{21}$ at P and Q respectively produced by the electric currents I_2 and I_1. What are the directions of these fields?

Define the SI unit of currents using the alongside set-up.



Ans : Main 2007

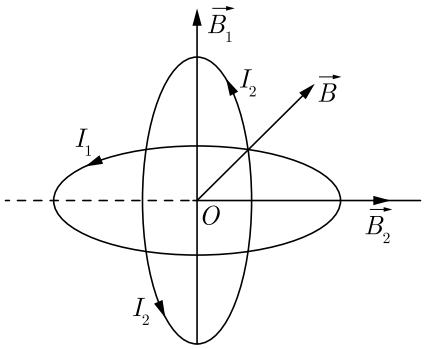
$$\vec{B}_{12} = \frac{\mu_0 I_2}{2\pi d},\ \vec{B}_{21} = \frac{\mu_0 I_1}{2\pi d}$$

The direction of field at P is perpendicular to the plane of the paper and outwards. The direction of field at Q is perpendicularly inwards to the plane of paper.

One ampere is that value of steady current which on flowing in each of two parallel infinitely long conductors of negligible cross-section placed in vacuum at a distance of 1 m from each other, produces a force of 2×10^{-7} newton per metre between them.

115. Two identical coils, each of radius R and number of turns N are lying in perpendicular planes such that their centres coincide. Find the magnitude and direction of the resultant magnetic field at the centre of the coils, if they are carrying currents I and $\sqrt{3}\,I$ respectively.

Ans : Comp 2008



Here, $I_1 = I,\ I_2 = \sqrt{3}\,I,\ N_1 = N_2 = N$

$R_1 = R_2 = R$

The magnetic field induction at the centre O of two concentric coils inclined at 90° is

$$B = \sqrt{B_1^2 + B_2^2}$$

$$B = \sqrt{\left(\frac{\mu_0 N_1 I_1}{2R_1}\right)^2 + \left(\frac{\mu_0 N_2 I_1}{2R_2}\right)^2}$$

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Its direction is perpendicular to the plane containing $\vec{dl}$ and $\vec{r}$ in vector form

$$\vec{dB} \propto \frac{I\vec{dl} \times \vec{r}}{r^3}$$

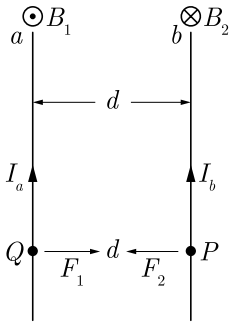
$$\vec{dB} = \frac{\mu_0}{4\pi} \cdot \frac{I\vec{dl} \cdot \vec{r}}{r^3}$$

($\vec{dl}$ is directed along the length of the wire in the direction of current and $\vec{r}$ is the vector joining the centre of current element to the point P)

110. Two long straight parallel conductors a and b carrying steady currents I_a and I_b respectively are separated by a distance d. Write the magnitude and direction, what is the nature and magnitude of the force between the two conductors?

Ans : **SQP 2011**

Let, a and b be two long straight parallel conductors I_a and I_b are the current flowing through them and separated by a distance d. Magnetic field induction at a point P on a conductor b due to current I_a passing through a is



$$B_1 = \frac{\mu_0 2I_a}{4\pi d}$$

Now, unit length of b will experience a force as

$$F_2 = B_1 I_b \times 1 = B_1 I_b$$

$$F_2 = \frac{\mu_0}{4\pi}\frac{2I_a I_b}{d}$$

Conductor a also experiences the same amount of force directed towards b. Hence, a and b attract each other.

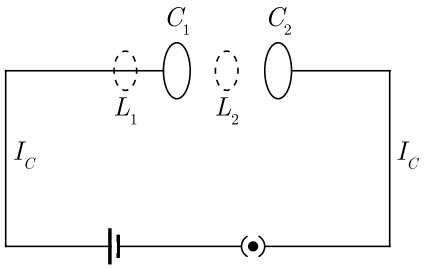
111. Show how the equation for Ampere's circuital law, viz.

$$\oint \vec{B} \cdot \overrightarrow{dl} = \mu_0 I$$

is modified in the presence of displacement current.

Ans : **Main 2019**

During charging of a capacitor, let at any instant transient current (I_C) flows through the wire.



Applying Ampere's circuital law for loops L_1 and L_2, we get

$$\oint_{L_1} \vec{B} \cdot \overrightarrow{dl} = \mu_0 I_C$$

$$\oint_{L_2} \vec{B} \cdot \overrightarrow{dl} = \mu_0 \times 0 = 0$$

This violates the concept of continuity of electric current. Maxwell introduced the concept of displacement current flowing in space due to varying electric field such that

$$I_C = I_D = \varepsilon_0 \frac{d\phi_E}{dt}$$

This maintained continuity of current.

Hence, Modified Ampere's circuital law is given by,

$$\oint \vec{B} \cdot \overrightarrow{dl} = \mu_0 (I_C + I_D)$$

112. Compare between moving coil galvanometer and moving magnet galvanometer.

Ans : **Main 2009, 2001**

The difference between moving coil galvanometer and moving magnet galvanometer are as follows :

	Moving Coil-Galvanometer	**Moving Magnet Galvanometer**
1.	The deflection in moving coil galvanometer is proportional to the current flowing through it.	It is also known as tangent galvanometer. The current flowing through the tangent galvanometer is directly proportional to the deflection in the coil.
2.	Its sensitivity is high.	Its sensitivity is low.
3.	A moving coil galvanometer is based on the principle of torque experienced by a current carrying coil placed in strong magnetic field.	Moving coil galvanometer is based on the tangent law.

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Hence, $\Delta B = \frac{\mu_0}{4\pi}\frac{Idl}{R^2}$

Resultant magnetic field,

$$B = \int \Delta B$$

$$= \int \frac{\mu_0 Idl}{4\pi R^2}$$

$$= \frac{\mu_0 I}{4\pi R^2}\int dl$$

For Semicircle, $\int dl = \pi R$

$$= \frac{\mu_0 I}{4\pi R^2} \times \pi R$$

$$= \frac{\propto_0 \cdot I}{\propto R}$$

119. Show that a tangent galvanometer measures that current with maximum accuracy which produces 45° deflection.

Ans : **Main 2013**

For a tangent galvanometer,

$$i = k\tan\theta \quad ...(1)$$

$$\frac{di}{d\theta} = k\sec^2\theta \quad \left[\text{Since}, \frac{d(\tan\theta)}{dt} = \sec^2\theta\right]$$

$$\frac{di}{i} = \frac{k\sec^2\theta d\theta}{i}$$

From Eq. (1), we get

$$\frac{di}{i} = \frac{k\sec^2\theta d\theta}{k\tan\theta}$$

$$\frac{di}{i} = \frac{1}{\cos^2\theta} \times \frac{\cos\theta d\theta}{\sin\theta}$$

$$\left[\text{Since}, \sec\theta = \frac{1}{\cos\theta}, \tan\theta = \frac{\sin\theta}{\cos\theta}\right]$$

$$\frac{di}{i} = \frac{d\theta}{\cos\theta\sin\theta}$$

$$\frac{di}{i} = \frac{2d\theta}{2\cos\theta\sin\theta}$$

$$\frac{di}{i} = \frac{2d\theta}{\sin 2\theta} \quad [\text{since } 2\theta = 2\sin\theta\cos\theta]$$

$$d\theta = \frac{\sin 2\theta di}{2i}$$

When $\sin 2\theta$ would be maximum than the tangent galvanometer has maximum,

$$\sin 2\theta = 1$$

$$2\theta = \sin^{-1}1$$

$$2\theta = \sin^{-1}\sin 90^\circ \quad [\text{Since}, \sin 90 = 1]$$

$$\theta = \frac{90}{2} = 45^\circ$$

120. Write the expression for the generalised for of Ampere's circuital law. Discuss its significance and describe briefly how the concept of displacement current is explained through charging/discharging of a capacitor in an electric circuit.

Ans : **Main 2015, 2013**

The generalised form of Ampere's circuital law, modified by Maxwell states that

$$\oint \vec{B}\cdot\vec{dl} = \mu_0(I_C + I_D)$$

$$= \mu_0\left(1 + \varepsilon_0\frac{d\phi_E}{dt}\right)$$

While dealing with the charging of a parallel plate capacitor with varying current. It was found that Ampere's circuital law is not logically consistent, because $\oint \vec{B}\cdot\vec{dl}$ has not the same value on the two sides of a plate of charged capacitor. The inconsistency of Ampere's circuital law was removed by Maxwell by predicting the presence of displacement current in the region between the plates of capacitor, when the charge on the capacitor is changing with time. So, displacement current is the missing term (which is related with the changing electric field which passes through the surface between the plates of capacitor).

In this way, Maxwell pointed out that for consistency of Ampere's circuital law, there must be displacement current I_D along with the conduction current in the closed loop as $(I_C + I_D)$ has the property of continuity.

121. Considering the case of a parallel plate capacitor being charged, show how one is required to generalise Ampere's circuital law to include the term due to displacement current.

Ans : **Main 2017, 2010**

Ampere's circuital law conduction current during charging of a capacitor was found inconsistent. Therefore, Maxwell modified Ampere's circuital law by introducing displacement current.

Ampere's circuit law

$\oint \vec{B}\cdot\vec{dl} = \mu_0 I$ was modified to

$\oint \vec{B}\cdot\vec{dl} = \mu_0(I_C + I_D)$

It is called modified Ampere's circuital law or Ampere-Maxwell's circuital law.

The displacement current arising due to time varying electric field is given by $I_D = \varepsilon_0\frac{d\phi_E}{dt}$

Therefore, modified Ampere's circuital law may be expressed as

$$\oint \vec{B}\cdot\vec{dl} = \mu_0 I\left(I_C + \varepsilon_0\frac{d\phi_E}{dt}\right)$$

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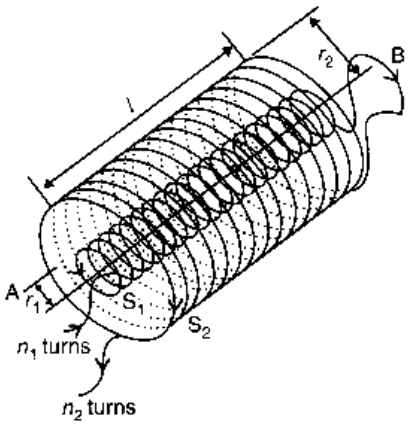
$$= \sqrt{\frac{\mu_0^2 N^2 I^2}{4R^2} + \frac{\mu_0 N(\sqrt{3}\, I)^2}{4R^2}}$$

$$= \frac{\mu_0 NI}{2R}\sqrt{1+3} = \frac{\mu_0 NI}{R}$$

116. Two long co-axial insulated solenoids S_1 and S_2 of equal length are wound one over the other as shown in the figure. A steady current I flows through the inner solenoid S_1 to the other end B which is connected to the outer solenoid S_2 through which the same current I flows in the opposite direction so, as to come out at end A. If n_1 and n_2 are the number of turns per unit length, find the magnitude and direction of the net magnetic field at a point

(a) inside on the axis and

(b) outside the combined system.



Ans : SQP 2006, 2005

According to Ampere's circuital law, the net magnetic field is given by $B = \mu_0 n\hat{i}$.

(a) The net magnetic field is given by

$$B_{\text{net}} = B_2 - B_1$$

$$= \mu_0 n_2 I_2 - \mu_0 n_1 I_1 \text{ [since, } I_2 = I_1 = I]$$

$$= \mu_0 I(n_2 - n_1)$$

The direction is form B to A.

(b) As the magnetic field due to S_1 is confined solely inside S_1 as the solenoids are assumed to be very long. So, there is no magnetic field outside S_1 due to current in S_1, similarly there is no field outside S_2.

Hence, $B_{\text{net}} = 0$

117. Define magnetic field in terms of the force on a moving charge. Hence define one tesla.

Ans : Comp 2020

We know that,

$$B = \frac{F}{qv\sin\theta}$$

If $q = 1,\ v = 1,$

$$\theta = 90^\circ$$

$$\sin 90^\circ = 1$$

Then, $B = F$

Thus the magnetic field at a point may be defined as the force acting on a unit charge moving with a unit velocity at right angles to the direction of the field.

SI Unit of Magnetic Field

Again, $B = \frac{F}{qv\sin\theta}$

If $F = 1\,\text{N}$, $q = 1\,\text{C}$, $v = 1\,\text{ms}^{-1}$ and $\theta = 90^\circ$, then

Hence, SI unit of $B = \frac{1\,\text{N}}{1\,\text{C}\cdot 1\,\text{ms}^{-1}\cdot\sin 90^\circ}$

$$= \frac{1\,\text{N}}{1\,\text{A}\cdot 1\text{m}} \text{ [since } \text{Cs}^{-1} = \text{A}]$$

$$= 1\text{NA}^{-1}\text{m}^{-1} = 1 \text{ teals}$$

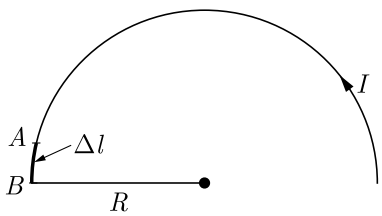
Thus the SI unit of magnetic field is teals (T).

One teals is that magnetic field in which a charge of 1 C moving with a velocity of $1\,\text{ms}^{-1}$ at right angles to the field experiences a force of one newton.

118. Applying Biot - Savart's law deduce the expression for the magnetic field at the centre of a semicircular loop of radius R carrying current I.

Ans : SQP 2024, 2020

Consider a semicircular coil of radius R carrying current I in anti-clock wise direction as shown in the figure according to Biot Savart's law the magnetic field due to current element AB at centre O is,



$$\Delta B = \frac{\mu_0}{4\pi}\frac{I\Delta l\sin\theta}{R^2}$$

where θ is angle between current element AB and the line joining the element to centre O.

Here, $\theta = 90^\circ$

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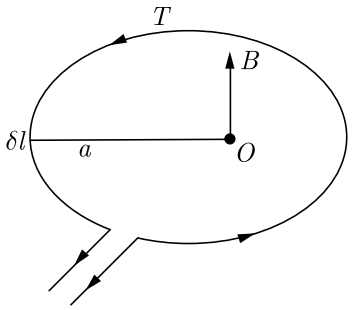


$$\delta B = \frac{\mu_0}{4\pi}\frac{I\delta l \sin\theta}{a^2}$$

Where, θ is the angle between the length of the element (δl) and the line joining the element to the point O. Here, $\theta = 90°$ (every element of a circle is perpendicular to the radius). Therefore, $\delta B = \frac{\mu_0}{4\pi}\frac{I\delta l}{a^2}$.The direction of the field will be the same for all elements of the coil. Therefore, the magnitude of the magnetic field $\vec{B}$ at O due to the entire coil is

$$B = \frac{\mu_0}{4\pi}\frac{I}{a^2}\Sigma\delta l$$

But $\Sigma\delta l = 2\pi a$ (the length of the circumference of the coil).

$$B = \frac{\mu_0}{4\pi}\frac{I}{a^2}(2\pi a)$$

or $$B = \frac{\mu_0 I}{2a}$$

If the circular coil has N turns, then the field at the centre would be

$$B = \frac{\mu_0 NI}{2a}$$

The magnetic field $\vec{B}$ is perpendicular to the plane of the coil, directed upwards. If the current in the coil be reversed, the field will be directed downwards.

125. Obtain an expression for magnetic flux density B at the centre of a circular coil of radius R having N turns and carrying a current I.

Ans : **Main 2015, 2011**

Consider a circular coil of radius R and carrying a current I in the direction as shown in figure. Suppose, the entire circular coil is divided into a large number of current elements, each of length dl.

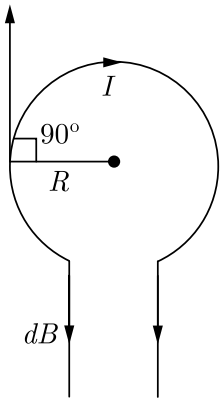
According to Biot-Savart's law, the magnetic field $d\vec{B}$ at the centre O of the coil due to the current element Idl is given by

$$\vec{B} = \frac{\mu_0}{4\pi}\frac{I(d\vec{l}\times\vec{R})}{R^3}$$

The magnitude of $d\vec{B}$ at the centre O is

$$dB = \frac{\mu_0}{4\pi}\cdot\frac{Idl\times R\sin\theta}{R^3}$$

$$dB = \frac{\mu_0}{4\pi}\frac{Idl\sin\theta}{R^2}$$



$$B = \int dB = \int \frac{\mu_0}{4\pi}\frac{Idl\sin\theta}{R^2}$$

$$\theta = 90° \Rightarrow \sin 90° = 1$$

$$B = \frac{\mu_0}{4\pi}\frac{1}{R^2}\int dl$$

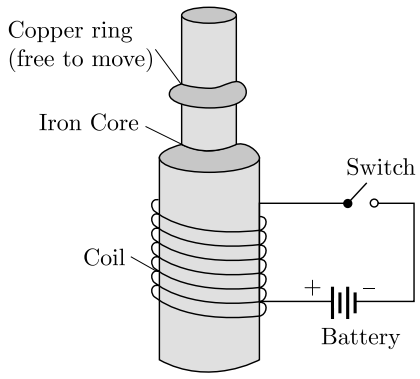
$$\int dl = \text{total length of the coil} = 2\pi r$$

$$B = \frac{\mu_0}{4\pi}\frac{1}{R^2}(2\pi R) = \frac{\mu_0 I}{2R}$$

If the coil has N turns, then

$$B = \frac{\mu_0 NI}{2R}$$

126. Consider the experimental set up shown in the figure. This jumping ring experiment is an outstanding demonstration of some simple laws of Physics. A conducting non-magnetic ring is placed over the vertical core of a solenoid. When current is passed through the solenoid, the ring is thrown off.



NODIA

Ans : **Main 2016**

This is because the charge particle moves on a circular path.

$$\vec{F} = q(\vec{v} \times \vec{B})$$

and power dissipated

$$\begin{aligned} P &= \vec{F} \times \vec{v} \\ &= q(\vec{v} \times \vec{B}) \times \vec{v} \\ &= q(\vec{v} \times \vec{v}) \times \vec{B} \quad (\text{since } \vec{v} \times \vec{v} = 0) \\ &= 0 \end{aligned}$$

The particle does not gain any energy.

101. A magnetic field that varies in magnitude from point to point but has a constant direction (east to west) is set up in a chamber. A charged particle enters the chamber and travels deflected along a straight path with constant speed. What can you say about the direction of initial velocity of the particle?

Ans : **SQP 2013, 2009**

Magnetic force on the particle,

$$F_m = qvB\sin\theta$$

The particle will remain undeflected if,

$$\begin{aligned} \sin\theta &= 0 \\ \theta &= 0^\circ \text{ or } 180^\circ \end{aligned}$$

Therefore, the initial velocity of the particle should be parallel or anti-parallel to the magnetic field (i.e., either east to west or west to east).

102. Two particles A and B of masses m and $2m$ have charges q and $2q$ respectively. They are moving with velocities v_1 and v_2 respectively. in the same direction, enters the same magnetic field B acting normally to their direction of motion. If the two forces F_A and F_B acting on them are in the ratio of 1 : 2, find the ratio of their velocities.

Ans : **Comp 2019**

Ratio of forces acting on the two particles,

$$\frac{F_A}{F_B} = \frac{qv_1B\sin 90^\circ}{(2q)\,v_2B\sin 90^\circ}$$

$$= \frac{1}{2} = \frac{v_1}{2v_2} \quad [\text{According to the question}]$$

$$\frac{v_1}{v_2} = 1$$

$$v_1 : v_2 = 1:1$$

103. A circular coil of closely wound N turns and radius r carries a current I. Write the expressions for the following:

1. The magnetic field at its centre.
2. The magnetic moment of this coil.

Ans : **Main 2013**

1. Magnetic field at centre due to circular current carrying coil,

$$B = \frac{\mu_0 NI}{2r}$$

2. Magnetic moment,

$$\begin{aligned} M &= NIA = NI(\pi r^2) \\ &= \pi NIr^2 \end{aligned}$$

where, r is the radius of circular coil, μ_0 is permeability of free space and N is number or turns.

104. Explain, giving reasons, the basic difference in converting a galvanometer into (1) a voltmeter and (2) an ammeter.

Ans : **Main 2024**

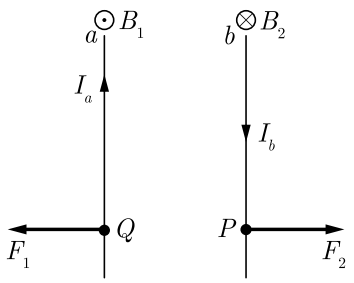
1. In converting a galvanometer into a voltmeter, a very high suitable resistance is connected in series to its coil. So, the galvanometer gives full scale deflection.
2. In converting a galvanometer into an ammeter, a very small suitable resistance is connected in parallel in parallel to its coil. The remaining pair of the current i.e., $(I - I_g)$ flows through the resistance.

Here, $I =$ Circuit current

and $I_g =$ Current through galvanometer

105. Show with the help of a diagram, how the force between the two conductors would change when the currents in them flow in the opposite directions.

Ans : **Main 2015**



Now, let the direction of current in conductor b be reversed. The magnetic field B_2 at point P due to current I_a flowing through a will be downwards. Similarly, the magnetic field B_1 at point Q due to current I_b passing through b will also be downward as shown. The force on a will be, therefore towards the left. Also, the force on b will be towards the right. Hence, the two conductors will repel each other as shown.

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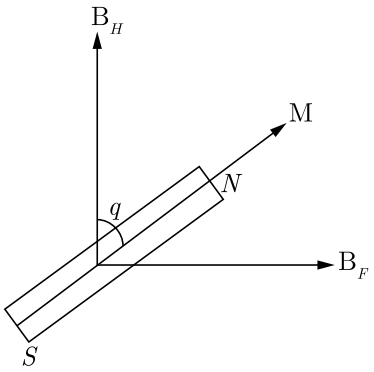
(i) We know that torque on a magnetic dipole placed in a uniform magnetic field $\vec{B}$ is $\tau = \vec{M} \times \vec{B}$, where,
$M =$ magnetic dipole moment and B is magnetic field.
The diagram (below) shows the situation given in question.



Torque due to $\vec{B}_H$ is anti-clockwise and due to $\vec{B}_F$ is clockwise.

(ii) In equilibrium, $|\tau_{B_H}| = |\tau_{B_F}|$

$$MB_H \sin\theta = MB_F \sin(90-\theta)$$

$$\tan\theta = \frac{B_F}{B_H}$$

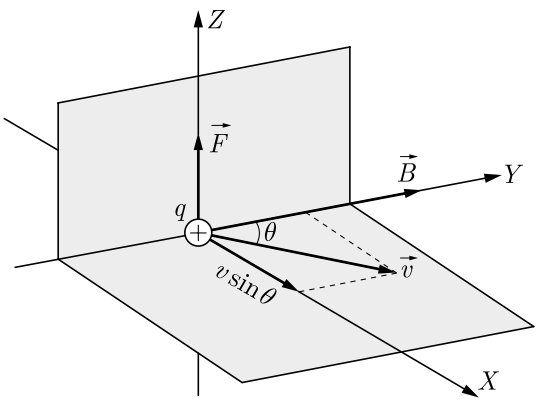
$$\theta = \tan^{-1}\left(\frac{B_F}{B_H}\right)$$

Here, $\vec{M}$ represents the magnetic moment.

129. State the factors on which the force acting on a charge moving in a magnetic field depends. Write the expression for this force. When is this force minimum and maximum?

Ans : **Main 2019**

As shown in figure, suppose a charge q moves with velocity $\vec{v}$ in a magnetic field $\vec{B}$ at angle θ.



Magnetic Lorentz Force

Form experiments, it is found that the charge q experiences a force $\vec{F}$ such that,

1. The force is proportional to the magnitude of the magnetic field, i.e., $F \propto B$
2. The force if proportional to the charge q, i.e., $F \propto q$
3. The force is proportional to the component of the velocity v in the perpendicular direction of the field B, i.e., $F \propto v \sin\theta$

Combining the above factors, we get

$$F \propto Bqv \sin\theta$$

$$F = kqvB \sin\theta$$

The unit of magnetic field is so defined that the proportionality constant k becomes unity in the above equation. Then

$$F = qvB \sin\theta$$

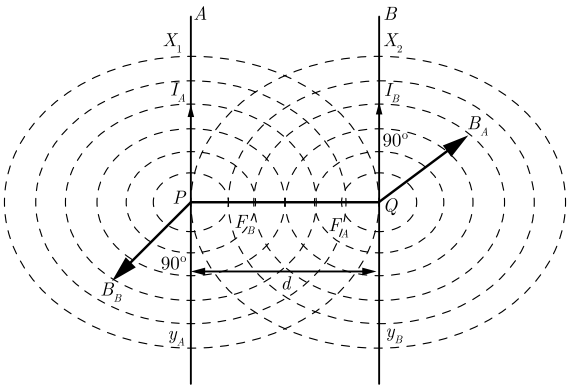
As the direction of $\vec{F}$ is perpendicular to both $\vec{v}$ and $\vec{B}$, so we can express $\vec{F}$ as

$$\vec{F} = q(\vec{v} \times \vec{B})$$

130. Two long parallel conductors A and B separated by a distance (d) carry steady currents I_A and I_B respectively. Show, by using Biot-Savart law and the Lorentz force that the magnitude of the force on a segment L of conductor B due to A is given by $F_{BA} = \frac{\mu_0 I_A I_B L}{2\pi d}$

Ans : **Main 2024, 2012**

Consider two parallel conductors A and B of length l long carrying currents I_A and I_B in same direction placed in vacuum at a distance d apart.



Magnetic field due to current I_A flowing through conductor A is given by

$$B_A = \frac{\mu_0 I_A}{2\pi d} \quad ...(1)$$

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(ii) A component of velocity of charge particle is parallel to the direction of the force of the electric field, the force experienced due to that component will be zero. This is because $F = qvB\sin 0^\circ = 0$. Thus, particle will move in straight line.

Also, the force experienced by the component perpendicular to $\vec{B}$ moves the particle in a circular path. The combined effect of both the components will move the particle in a helical path.

(iii) Magnetic force on the charge, q

$$\vec{F}_B = q(\vec{v} \times \vec{B})$$
$$= q[v(-\hat{i}) \times B(-\hat{k})]$$

Hence, for moving charge, q in its original path

$$\vec{F}_E + \vec{F}_B = 0$$
$$\vec{F}_B = qvB(-\hat{j})$$

Hence, $$\vec{E} = vB(-\hat{j})$$

Taking magnitude both side,

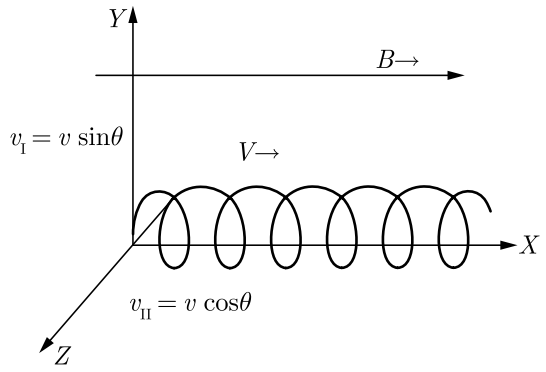
$$|\vec{E}| = q\frac{vB}{q} = vB$$

Direction of Lorentz magnetic force is negative along Y-axis.

Therefore, direction of $\vec{E}$ is positive along Y-axis.

139. A uniform magnetic field $\vec{B}$ is set up along the positive X-axis. A particle of charge q and mass m moving with a velocity v enters the field at the origin in XY-plane such that it has velocity components both along and perpendicular to the magnetic field $\vec{B}$. Trace, giving reason, the trajectory followed by the particle. Find out the expression for the distance moved by the particle along the magnetic field in one rotation.

Ans : **SQP 2015, 2011**



The path of the charged particle will be helix. As, the charge moves linearly in the direction of the magnetic field with velocity $v\cos\theta$ and also describe the circular path due to velocity $v\sin\theta$.

Time taken by the charge to complete one circular rotation,

$$T = \frac{2\pi r}{v_I}$$
$$f = qv_I B \quad ...(1)$$

and $$\frac{mv_I^2}{r} = qv_I B \quad ...(2)$$

From equation (1) and (2), we get

$$\frac{v_I^2 m}{r} = qv_I B$$
$$\frac{v_I m}{qB} = r$$
$$T = \frac{2\pi v_I m}{qB \cdot v_I}$$
$$T = \frac{2\pi m}{Bq}$$

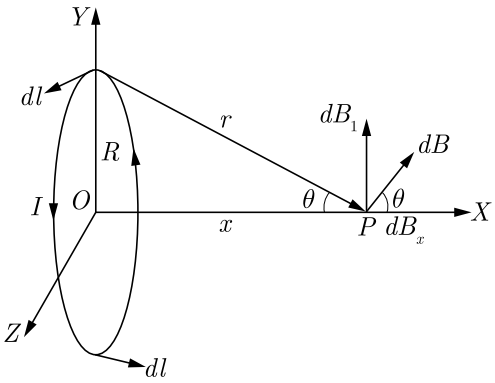
Distance moved by the particle along the magnetic field in one rotation (pitch of the helix path)

$$= v_{II} \times T \quad (\text{since } v_{II} = v_{\text{parallel}})$$
$$= v_{\cos\theta} \times \frac{2\pi m}{Bq}$$
$$P = \frac{2\pi m v\cos\theta}{qB}$$

140. Using Biot-Savart's law, derive the expression for the magnetic field in the vector form at a point on the axis of a circular current carrying loop.

Ans : **Comp 2013**

Magnetic field on the axis of a circular current loop.



I → Current in the loop,

R → Radius of the loop,

X-axis → Axis of the loop,

x → Distance OP

dl → Conducting element of the loop

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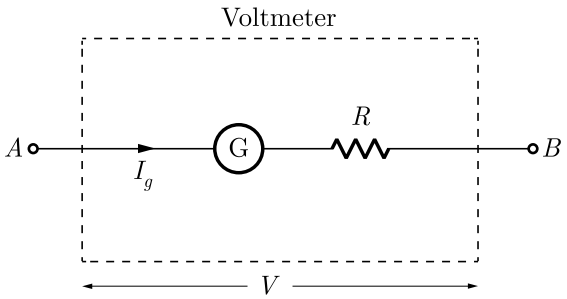
133. How can a galvanometer of resistance G be converted into a voltmeter to read a maximum potential difference of V volts? Support your answer with related mathematical expression.

Ans : **Comp 2012**

A galvanometer can be used as a voltmeter to measure voltage across any circuit element. For this it must be connected in parallel with that element. Further, it must draw a very small current, otherwise the voltage required to be measured will decrease substantially. To ensure this, a large resistance R is connected in series with the galvanometer.



Conversion of a Galvanometer into a Voltmeter

Let, G = resistance of the galvanometer

I_g = the current with which galvanometer gives full scale deflection

$0 - V$ = required range of the voltmeter and

R = the high series resistance which restricts the current to safe limit I_g

Hence, total resistance in the circuit $= R + G$

By Ohm's law,

$$I_g = \frac{\text{Potential difference}}{\text{Total resistance}}$$

$$= \frac{V}{R+G}$$

$$R + G = \frac{V}{I_g}$$

$$R = \frac{V}{I_g} - G$$

So by connecting a high resistance R in series with the galvanometer, we get a voltmeter of desired range. Hence a voltmeter is a high resistance galvanometer. Its effective resistance is,

$$R_V = R + G >> G$$

134. A straight wire of length L is bent into a semi-circular loop. Use Biot-Savart's law to deduce an expression for the magnetic field at its centre due to the current I passing through it.

Ans : **Main 2011**

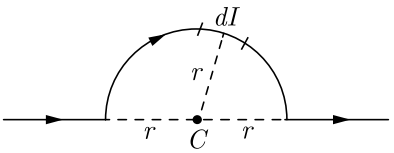
When a straight was is bent into semi-circular loop, then there are two parts which can produce the magnetic field at the centre one is circular part and other is straight part due to which field is zero.

Length L is bent into semi-circular loop.

Length of wire = Circumference of semi-equal circular wire

$$L = \pi r$$

$$r = \frac{L}{\pi} \quad ...(1)$$



Considering a small element dl on current loop. The magnetic field dB due to small current element Idl at centre C.

Using Biotech-Savart's law, we have

$$dB = \frac{\mu_0}{4\pi} \cdot \frac{Idl \sin 90^\circ}{r^2}$$

[since $Idl \perp r$, hence $\theta = 90^\circ$]

$$dB = \frac{\mu_0}{4\pi} \cdot \frac{Idl}{r^2}$$

Net magnetic field at C due to semi-circular loop,

$$B = \int_{\text{semi-circle}} \frac{\mu_0}{4\pi} \frac{Idl}{r^2}$$

$$B = \frac{\mu_0}{4\pi} \frac{I}{r^2} \int_{\text{semi-circle}} dl$$

$$B = \frac{\mu_0}{4\pi} \cdot \frac{I}{r^2} L$$

But, $r = \frac{L}{\pi}$

$$B = \frac{\mu_0}{4\pi} \cdot \frac{IL}{(L/\pi)^2}$$

$$= \frac{\mu_0}{4\pi} \times \frac{IL}{L^2} \times \pi^2$$

$$B = \frac{\mu_0 I \pi}{4L}$$

This is the required expression.

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Now, we can say that conductor $x_B y_B$ carrying current I_B is placed in magnetic field B, so force per unit length acting on it be F_A (since $F = ILB\sin\theta$), where $\theta = 90^\circ$

$$F_A = I_B B_A = \frac{\mu_0}{4\pi} \cdot \frac{2I_A I_B}{d}$$

$$= \frac{\mu_0 I_A I_B}{2\pi d} \quad ...(2)$$

Similarly, magnetic field due to I_B flowing through conductor B is given by,

$$B_B = \frac{\mu_0 I_B}{2\pi d}$$

and force F_B on A will be

$$F_B = I_A B_B = I_A \frac{\mu_0 I_B}{2\pi d}$$

$$= \frac{\mu_0 \cdot I_A I_B}{2\pi d} \quad ...(3)$$

It is clear from equations (2) and (3), forces F_A and F_B are equal and opposite in direction (B_1 and B_2 are parallel but opposite in direction).

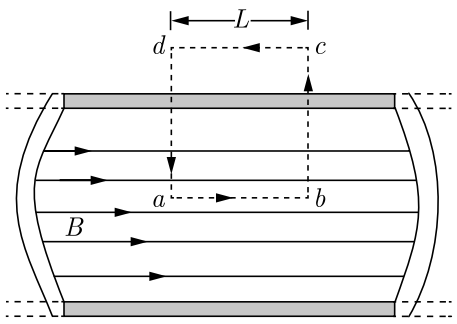
Hence, force between two parallel current carrying conductors on a segment L of conductor B due to A is given by

$$F = \frac{\mu_0 I_A I_B}{2\pi d}$$

131. A long solenoid of length L having N turns carries a current I. Deduce the expression for the magnetic field in the interior of the solenoid.

Ans : **Comp 2018, 2015**

Consider a rectangular path $abcd$ of length L as shown in figure below. Let us apply Ampere's circuital law to this rectangular path, so that, we have



$$\oint \vec{B}\cdot\vec{dL} = \int_a^b \vec{B}\cdot\vec{dL} + \int_b^c \vec{B}\cdot\vec{dL} + \int_c^d \vec{B}\cdot\vec{dL} + \int_d^a \vec{B}\cdot\vec{dL}$$

$$= \int_a^b \vec{B}\cdot\vec{dL} + 0 + 0 + 0 = BL \quad ...(1)$$

Since, $\int_b^c \vec{B}\cdot\vec{dL} = \int_d^a \vec{B}\cdot\vec{dL} = 0$ [since, $\phi = 90^\circ$]

$$\int_c^d \vec{B}\cdot\vec{dL} = 0 \quad \text{[since, } B = 0\text{]}$$

But by Ampere's circuital law, we have

$$\oint \vec{B}\cdot\vec{dL} = \mu_0 NI = \mu_0 (nL) I \quad ...(2)$$

From equations (1) and (2), we have

$$BL = \mu_0 nLI$$

or $$B = \mu_0 nI$$

But $n = N/I$, therefore, we have

$$B = \mu_0 \frac{NI}{L}$$

This gives the value of magnetic field inside a solenoid.

132. A galvanometer of resistance G is converted into a voltmeter to measure upto V volts by connecting a resistance R_1 in series with the coil. If a resistance R_2 is connected in series with it, then it can measure upto $V/2$ volts. Find the resistance, in terms of R_1 and R_2, required to be connected to convert it into a voltmeter that can read upto 2 V. Also find the resistance G of the galvanometer in terms of R_1 and R_2.

Ans : **SQP 2015, 2011**

Let I_g be the current through galvanometer at full deflection to measure V volts,

$$V = I_g(G + R_1) \quad ...(1)$$

According to question

$$\frac{V}{2} = I_g(G + R_2) \quad ...(2)$$

$$2\text{ V} = I_g(G + R_3) \quad ...(3)$$

To measure for conversion of range dividing equation (1) by equation (2),

$$2 = \frac{G + R_1}{G + R_2}$$

$$G = R_1 - 2R_2$$

Putting the value of G in equation (1), we have

$$I_g = \frac{V}{R_1 - 2R_2 + R_1}$$

$$I_g = \frac{V}{2R_1 - 2R_2}$$

Substituting the value of G and I_g in equation (3), we have

$$2\text{ V} = \frac{V}{2R_1 - 2R_2}(R_1 - 2R_2 + R_3)$$

$$4R_1 - 4R_2 = R_1 - 2R_2 + R_3$$

$$R_3 = 3R_1 - 2R_2$$

NODIA

(ii) Considering a loop of radius r whose centre lies at the axis of wire and $(r > a)$ as shown in outer dotted line. Current I threads the loops. Applying Ampere's circuital law,

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 I$$

$$\oint B dl \cos 0^\circ = \mu_0 I$$

$$B \oint dl = \mu_0 I$$

$$B \times 2\pi r = \mu_0 I$$

$$B = \frac{\mu_0 I}{2\pi r}$$

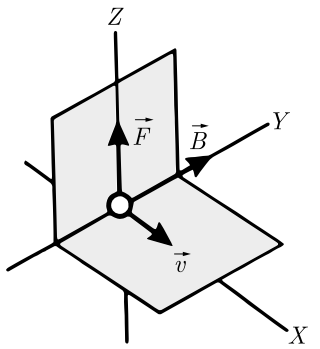
$$B \propto \frac{1}{r}$$

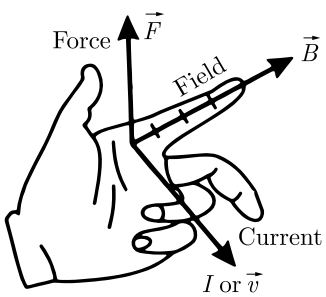
137. State the rules to find the direction of force on a charge moving in a perpendicular magnetic field.

Ans : **SQP 2017, 2012**

Rules for finding the direction of force on a charged particle moving perpendicular to a magnetic field:

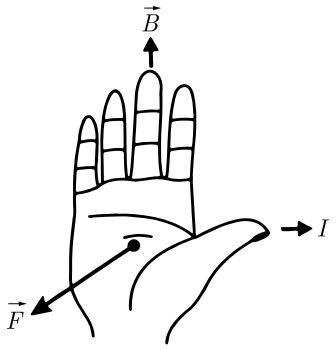
1. **Fleming's Left Hand Rule :** Stretch the thumb and the first two fingers of the left hand mutually perpendicular to each other. If the forefinger points in the direction of the magnetic field, central finger in the direction of current, then the thumb gives the direction of the force on the charged particle.





Fleming's Left Hand Rule

2. **Right Hand (palm) Rule :** Open the right hand and place it so that tips of the fingers point in the direction of the field $\vec{B}$ and thumb in the direction of velocity $\vec{v}$ of the positive charge, then the palm faces towards the force $\vec{F}$.

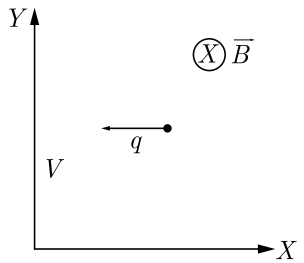


Right Hand Palm Rule

138. (i) A point charge q moving with speed V enters a uniform magnetic field B that is acting into the plane of the paper as shown. What is the path followed by the charge q and in which plane does it move ?

(ii) How does the path followed by the charge get affected it its velocity has a component parallel to $\vec{B}$?

(iii) If an electric field $\vec{E}$ is also applied such that the particle continues moving along the original straight line path, what should be the magnitude and direction of the electric field $\vec{E}$?



Ans : **SQP 2011**

(i) The force experienced by the charge particle is given by

$$\vec{F} = q(\vec{v} \times \vec{B})$$

When $\vec{v}$ is perpendicular to $\vec{B}$, the force on the charge particle acts as the centripetal force and makes it move along a circular path. Path followed by charge is anticlockwise in X - Y plane. The point charge moves in the plane perpendicular to both $\vec{v}$ and $\vec{B}$.

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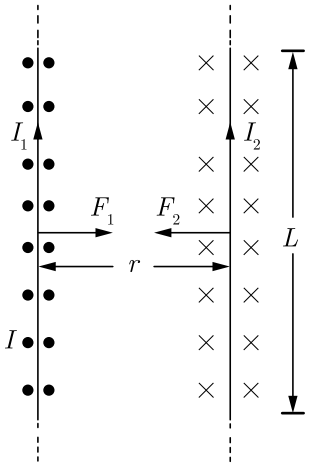
135. A steady current I_1 flows through a long straight wire. Another wire carrying steady current I_2 in the same direction is kept close and parallel to the first wire. Show with the help of a diagram, how the magnetic field due to the current I_1 exert a magnetic force on the second wire. Deduce the expression for this force.

Ans : **Main 2025, 2011**

Let two infinitely long straight current carrying conductor carry currents I_1 and I_2 in the same direction. Magnetic field B_1 due to first wire on seconds, i.e.,

$$B_1 = \frac{\mu_0}{4\pi}\frac{2I_1}{r} \quad ...(1)$$

The magnetic field is perpendicular to the plane of paper and directed inwards i.e., (X) type.



Now, magnetic force on L length of second wire is given by

$$F_2 = I_2 B_1 L \sin 90^\circ$$

$$F_2 = I_2\left(\frac{\mu_0}{4\pi}\cdot\frac{2I_1}{r}\right)L$$

$$\frac{F_2}{L} = \frac{\mu_0}{4\pi}\cdot\frac{2I_1I_2}{r} \quad ...(2)$$

By Fleming's left hand rule, the direction of force F_2 is perpendicular to the second wire in the plane of paper towards the first wire.

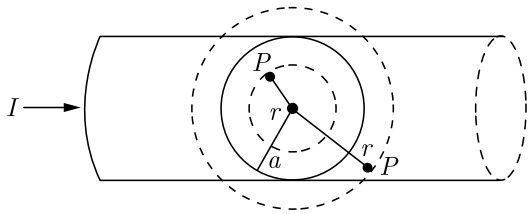
Similarly, magnetic force on Ist wire is given by

$$\frac{F_1}{L} = \frac{\mu_0}{4\pi}\cdot\frac{2I_1I_2}{r} \quad ...(3)$$

The force F_1 is directed towards the second wire.

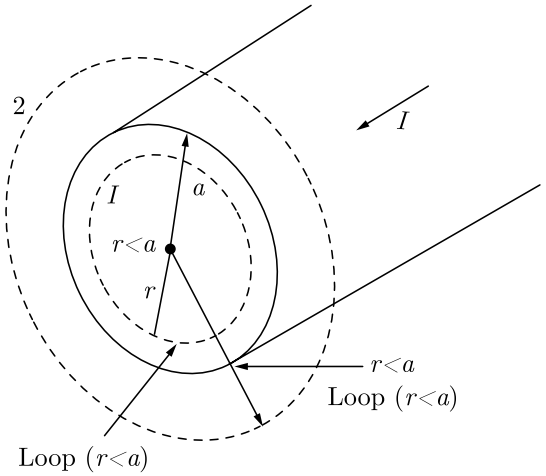
Thus, two straight parallel current carrying conductor have the same direction of flow of currents attracting each other.

136. Figure shows a long straight wire of a circular cross-section of radius a and carrying steady current I. The current I is uniformly distributed across this cross-section. Derive the expressions for the magnetic field in the region $r < a$ and $r > a$.



Ans : **Main 2019**

The current is distributed uniformly across the cross-section of radius a.



Current passes per unit in the cross-section $= \frac{I}{\pi a^2}$

Current passes through the cross-section of radius r is

$$I' = \left(\frac{I}{\pi a^2}\times \pi r^2\right) = \frac{Ir^2}{a^2} \quad ...(1)$$

(i) Consider a loop of radius r whose centre lies at the axis of wire where, $r < a$ as shown in figure inside the wire. Applying Ampere's circuital law,

$$\oint \vec{B}\cdot\vec{dl} = \mu_0 I'$$

$$\oint B dl\cos 0^\circ = \mu_0\left(\frac{Ir^2}{a^2}\right)$$

[From equation (1)]

$$B\oint dl = \mu_0\frac{Ir^2}{a^2}$$

$$B\times 2\pi r = \mu_0\frac{Ir^2}{a^2}$$

$$B = \frac{\mu_0 Ir^2}{2\pi a^2} \propto r$$

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According to Biot-Savart's law, the magnetic field at P is

$$dB = \frac{\mu_0 I\,|\,dl \times r\,|}{4\pi r^3}$$

$$r^2 = x^2 + R^2$$

$$dl \times r = r\,dl$$

[since, they are perpendicular]

$$dB = \frac{\mu_0}{4\pi} \cdot \frac{Idl}{(x^2+R^2)}$$

dB has two components $-dB_x$ and dB_1, dB_1 is cancelled out and only the x-component remains.

$$dB_x = dB\cos\theta$$

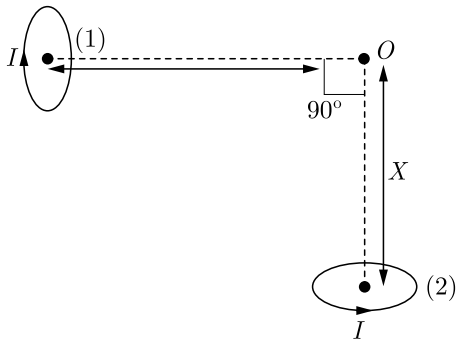
$$\cos\theta = \frac{R}{(x^2+R^2)^{1/2}}$$

Hence, $$dB_x = \frac{\mu_0 Idl}{4\pi} \cdot \frac{R}{(x^2-R^2)^{3/2}}$$

Summation of dl over the loop is given by $2\pi R$.

$$B = B_x\hat{i} = \frac{\mu_0 IR^2}{2\,(x^2+R^2)^{3/2}}\hat{i}$$

141. Two very small identical circular loop (1) and (2) carrying equal current I are placed vertically (with respect to the plane of the paper) with their geometrical axis perpendicular to each other as shown in the figure. Find the magnitude and direction of the net magnetic field produced at the point O.



Ans : SQP 2014, 2013

The magnetic field at a point due to a circular loop is given by

$$B = \frac{\mu_0}{4\pi} \cdot \frac{2\pi Ia^2}{(a^2+r^2)^{3/2}}$$

where, I = current through the loop

a = radius of the loop

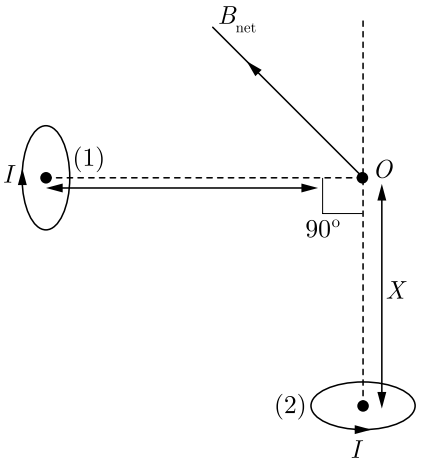
r = distance of O from the centre of the loop

Since, I, a and $r = x$ are the same for both the loops, the magnitude of B will be the same and is given by

$$B_1 = B_2 = \frac{\mu_0}{4\pi} \cdot \frac{2\pi Ia^2}{(a^2+x^2)^{3/2}}$$

The direction of magnetic field due to loop (1) will be away from O and that of the magnetic field due to loop (2) will be towards O as shown.

The direction of the net magnetic field will be as shown below



The magnitude of the net magnetic field is given by

$$B_{net} = \sqrt{B_1^2 + B_2^2}$$

$$B_{net} = \frac{\mu_0}{4\pi} \frac{2\sqrt{2\pi}\,Ia^2}{(a^2+x^2)^{3/2}}$$

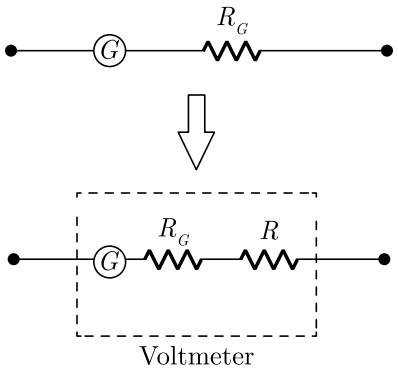
142. How is a galvanometer converted into a voltmeter and an ammeter ? Draw the relevant diagrams and find the resistance of the arrangement in each case. Take resistance of galvanometer as G.

Ans : Main 2016, 2023

A galvanometer is converted into a voltmeter by connecting a high resistance R in series with it.

A galvanometer is converted into an ammeter by connecting a small resistance (called shunt) in parallel with it.

Resistance of voltmeter, $R_V = G + R$



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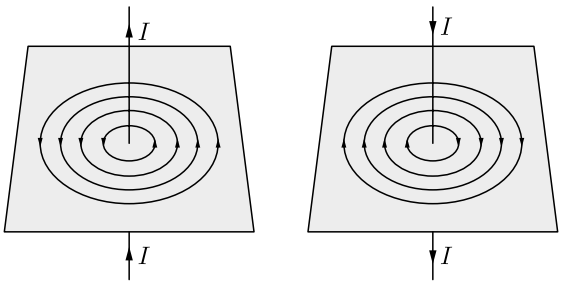
146. Sketch the magnetic lines of force of straight current carrying conductor. State the rules used to find the direction of this magnetic field.

Ans : Main 2021

Magnetic Field Pattern of a Straight Current Carrying Conductor

The magnetic lines of force of a straight current carrying conductor are concentric circles with the wire at the centre and in a plane perpendicular to the wire. If the current flows upwards, the lines of force have anticlockwise sense [Figure (a)] and if the current flows downwards, then the lines of force have clockwise sense [Figure (b)].

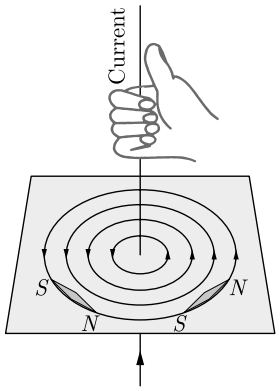


Magnetic Lines of Force of a Straight Current Carrying Conductor

Rules for Finding the Direction of Magnetic Field Due to Straight Current Carrying Conductor

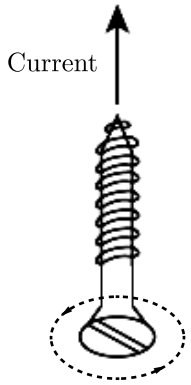
Either of the following two rules can be used for this purpose.

1. **Right Hand Thumb Rule :** If we hold the straight conductor in the grip of our right hand in such a way that the extended thumb points in the direction of current, then the direction of the curl of the fingers will give the direction of the magnetic field.



Right Hand Rule for Field Due to a Straight Conductor

2. **Maxwell's Cork Screw Rule :** If a right-handed screw be rotated along the wire so that it advances in the direction of current, then the direction in which the thumb rotates gives the direction of the magnetic field.

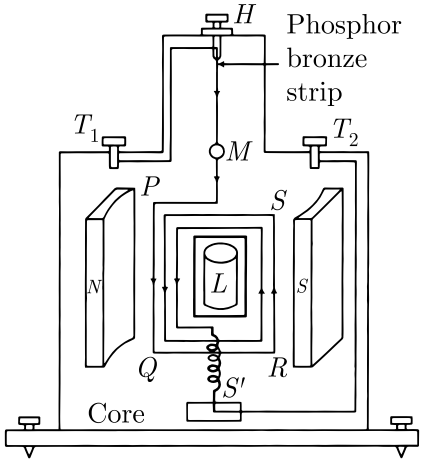


Cork Screw Rule for Field Due to a Straight Conductor

147. Explain principle and working of a moving coil galvanometer. Derive an expression for current sensitivity.

Ans : SQP 2006

Principle : Its working is based on the fact that when a current carrying coil is placed in a magnetic field, it experiences a torque.



Construction

The moving coil galvanometer consists of a coil with many turns free to rotate about a fixed axis, in a uniform radial magnetic field. There is a cylindrical soft iron core which not only makes the field radial but also increases the strength of the magnetic field. When a current flows through the coil, a torque acts on it.

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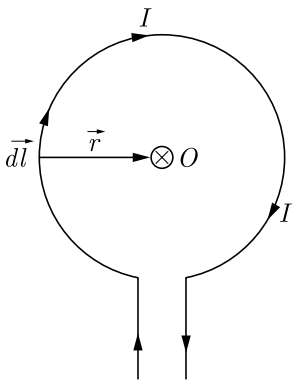
The direction of $\overrightarrow{dl}$ is along the tangent, so $\overrightarrow{dl} \perp \vec{r}$. From Bio-Savart law, magnetic field at the centre O due to this current element is

$$dB = \frac{\mu_0 I}{4\pi} \frac{dl \sin 90^\circ}{r^2} = \frac{\mu_0 I}{4\pi} \cdot \frac{dl}{r^2}$$



Magnetic Field at the Centre of a Circular Current Loop

The magnetic field due to all such current elements will point into the plane of paper at centre O as shown by encircled cross $\otimes$. Hence the total magnetic field at the centre O is,

$$B = \int dB = \int \frac{\mu_0 I}{4\pi} \cdot \frac{dl}{r^2}$$

$$= \frac{\mu_0 I}{4\pi r^2} \int dl$$

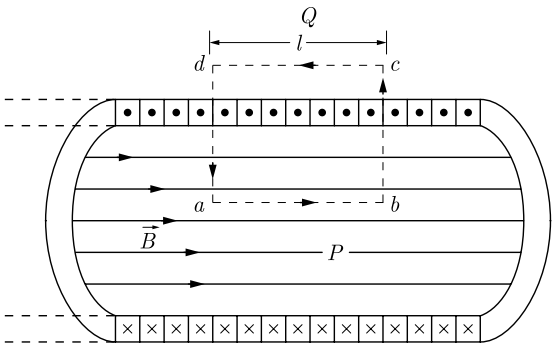
$$= \frac{\mu_0 I}{4\pi r^2} \cdot l = \frac{\mu_0 I}{4\pi r^2} \cdot 2\pi r$$

$$= \frac{\mu_0 I}{2r}$$

145. A long solenoid with closely wound turns has n turns, per unit of its length. A steady current I flows through this solenoid. Use Ampere's circuital law to obtain an expression, for the magnetic field, at a point on its axis and close to its midpoint.

Ans : **Comp 2020, 2017**

The magnetic field inside a closely wound long solenoid is uniform everywhere and zero outside it shows the sectional view of a long solenoid. At various turns of the solenoid, current comes out of the plane of paper at points marked $\odot$ and enters the plane of paper at points marked $\otimes$. To determine the magnetic field $\vec{B}$ at any inside point, consider a rectangular closed path $abcd$ as the Amperian loop. According to Ampere's circuital law,



The Magnetic Field of a very Long Solenoid

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 \times \text{Total current through the loop } abcd$$

Now,

$$\oint \vec{B} \cdot \vec{dl} = \int_a^b \vec{B} \cdot \vec{dl} + \int_b^c \vec{B} \cdot \vec{dl} + \int_c^d \vec{B} \cdot \vec{dl} + \int_d^a \vec{B} \cdot \vec{dl}$$

But, $\int_b^c \vec{B} \cdot \vec{dl} = \int_b^c Bdl \cos 90^\circ = 0$

$$\int_d^a \vec{B} \cdot \vec{dl} = \int_d^a Bdl \cos 90^\circ = 0$$

$$\int_c^d \vec{B} \cdot \vec{dl} = 0$$

As, $B = 0$ for points outside the solenoid.

Hence, $\oint \vec{B} \cdot \vec{dl} = \int_a^b \vec{B} \cdot \vec{dl}$

$$= \int_a^b Bdl \cos 0^\circ = B \int_a^b dl = Bl$$

where, l is length of the side ab of the rectangular loop $abcd$.

Let, number of turns per unit length of the solenoid $= n$. Then number of turns in length l of the solenoid $= nl$.

Hence, total current threading the loop $abcd$ $= nlI$.

Hence, $Bl = \mu_0 nlI$

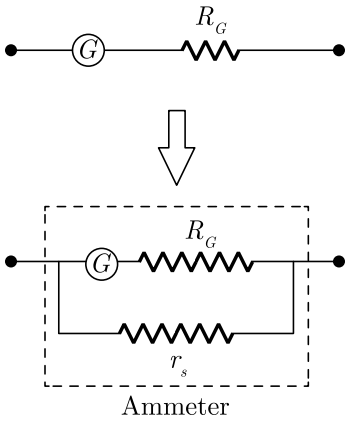
or $B = \mu_0 nI$

It can be easily shown that the magnetic field at the end of the solenoid is just one half of that at its middle. Thus,

$$B_{\text{end}} = \frac{1}{2}\mu_0 nI$$

NODIA

Resistance of Ammeter, $R_A = \dfrac{Gr_s}{G + r_s}$



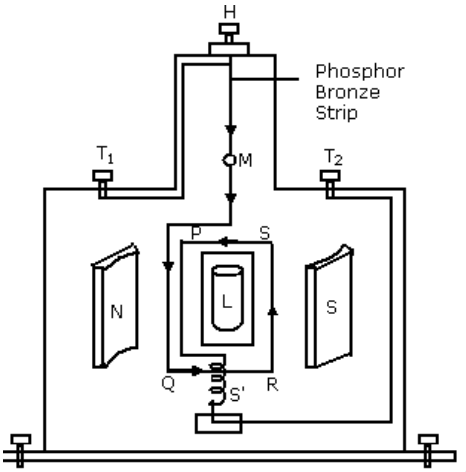
Ammeter

143. Obtain the formula, $I = k\theta$ for a moving coil galvanometer given the deflecting torque $\tau = \vec{M} \times \vec{B}$, where $\vec{M}$ is the magnetic dipole moment of the coil placed in the magnetic field $\vec{B}$, I is the current in the galvanometer and θ is the deflection.

Ans : **Main 2008**

The working of a moving coil galvanometer is based on the fact that when a current carrying coil is placed in a magnetic field, it experiences a net torque.

Consider the diagram, where the coil $PQRS_1$, is suspended freely in the magnetic field.



Let l = length PQ or RS of the coil

b = breadth QR or SP of the coil

N = number of turns in the coil

Area of each turn of the coil $A = l \times b$

Let B = strength of the magnetic field in which coil is suspended

I = current passing through the coil in the direction of $PQRS$

Let at any instant of time, α be the angle which the normal drawn to the plane of the coil makes with the direction of magnetic field.

The rectangular current carrying coil when placed in the magnetic field experiences a torque whose magnitude is given by, $\tau = NIBA\sin\alpha$

Due to this torque, the coil rotates and suspension wire gets twisted. A restoring torque is set up in the suspension wire.

Let θ be the twist produced in the phosphor bronze strip due to rotation of the coil and k be the restoring torque per unit twist of the phosphor bronze strip.

Then, total restoring torque produced $= k\theta$

In equilibrium position of the coil,

Deflection torque = Restoring torque

$$NIBA = k\theta \qquad [\alpha = 90^\circ]$$

or $$I = \frac{k}{NBA}\theta = G\theta$$

where, $$\frac{k}{NBA} = G$$

It is known as galvanometer constant.

$$I \propto \theta$$

Current is directly proportional to the deflection produced in the coil.

144. State the Bio-Savart law for the magnetic field due to a current carrying element. Use this law to obtain a formula for magnetic field at the centre of a circular loop of radius R carrying a steady current I. Indicate the direction of the magnetic field.

Ans : **Comp 2021**

According to Bio-Savart's law, the magnetic field due to a current element $\overrightarrow{dl}$ carrying current I at a point P at distance r from it is given by,

$$dB = \frac{\mu_0}{4\pi} \cdot \frac{Idl\sin\theta}{r^2}$$

where, μ_0 is permeability of free space and θ, is the angle between $\overrightarrow{dl}$ and $\vec{r}$.

Magnetic field at the centre of a circular current carrying coil: Consider a circular loop of wire of radius r carrying a current I. Consider a current element $\overrightarrow{dl}$ of the loop.

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Working

Suppose the coil $PQRS$ is suspended freely in the magnetic field. Let l be length PQ or RS of the coil, b be breadth QR or SP of the coil, N be number of turns in the coil and area of each turn of the coil, $A = l \times b$. Let B be strength of the magnetic field in which coil is suspended and I is current passing through the coil in the direction $PQRS$.

Let at any instant, α be the angle, which normal drawn on the plane of the coil makes with the direction of magnetic field. The rectangular coil carrying current when placed in the magnetic field experiences a torque whose magnitude is given by $\tau = NIBA\sin\alpha$. Due to deflecting torque, the coil rotates and suspension wire gets twisted. A restoring torque is set up in the suspension wire.

Let θ be the twist produced in the phosphor bronze strip due to rotation of the coil and k be the restoring torque per unit twist of the phosphor bronze stripe. The,

Total restoring torque produced $= k\theta$

In equilibrium position of the coil,

Deflecting torque = Restoring torque

$$NIBA = k\theta$$

$$I = \frac{k}{NBA}\theta = G\theta$$

where, $\frac{k}{NBA} = G$

It is known as galvanometer constant.

i.e. $\theta \propto I$. It means that the deflection produced is proportional to the current flowing through the galvanometer.

Current sensitivity

Current sensitivity of the galvanometer is the deflection per unit current flowing through it.

It is given by, $I_S = \frac{\theta}{I} = \frac{NAB}{k}$

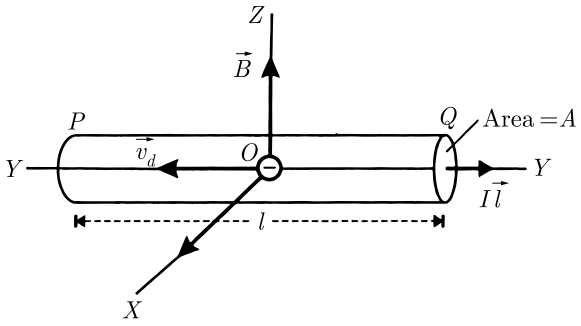
Its unit is rad/A or div/A.

148. Derive a mathematical expression for the force acting on a current carrying straight conductor kept in a magnetic field. State the rule used to determine the direction of this force. Under what conditions if this force (1) zero and (2) maximum?

Ans : **Main 2019, 2013**

As shown in figure, consider a conductor PQ of length l, area of cross-section A, carrying current I along +ve Y-direction. The field $\vec{B}$ acts along +ve Z-direction. The electrons drift towards left with velocity $\vec{v}_d$. Each electron experiences a magnetic Lorentz force along +ve X-axis, which is given by,

$$\vec{f} = -e(\vec{v}_d \times \vec{B})$$



Force on a Current in a Magnetic Field

In n is the number of free electrons per unit volume, then total number of electrons in the conductor is,

$$N = n \times \text{volume} = nAl$$

Total force on the conductor is,

$$\vec{F} = N\vec{f} = nAl[-e(\vec{v}_d \times \vec{B})]$$

$$= enA[-l\vec{v}_d \times \vec{B}]$$

If $I\vec{l}$ represents a current element vector in the direction of current, then vectors $\vec{l}$ and $\vec{v}_a$ will have opposite directions and we can take,

$$-l\vec{v}_d = v_d\vec{l}$$

Hence, $\vec{F} = enAv_d(\vec{l} \times \vec{B})$

$$\vec{F} = I(\vec{l} \times \vec{B}) \qquad [\text{since } enAv_d = I]$$

Magnitude of Force

The magnitude of the force on the current carrying conductor is given by

$$F = IlB\sin\theta$$

where θ is the angle between the direction of the magnetic field and the direction of flow of current.

1. If,

$$\theta = 0^\circ \text{ or } 180^\circ$$

Then, $F = IlB(0) = 0$

Thus a current carrying conductor placed parallel to the direction of the magnetic field does not experience any force.

2. If,

$$\theta = 90^\circ$$

Then, $F = IlB\sin 90^\circ = IlB$

$$F_{\max} = IlB$$

NODIA

Thus a current carrying conductor placed perpendicular to the direction of a magnetic field experience a maximum force.

Direction of Force :

The direction of force on a current carrying conductor placed in a perpendicular magnetic field is given by Fleming's left hand rule. Stretch the thumb and the first two fingers of the left hand in mutually perpendicular directions. If the forefinger points in the direction of the magnetic field, central finger in the direction of current, then the thumb gives the direction of force on the conductor. In figure the field $\vec{B}$ is along $+Z$ -direction, the current I along $+Y$-direction and so the force $\vec{F}$ acts along $+X$-direction.

149. Explain Biot-Savart law. Derive expression for the magnetic field at the centre of a current carrying circular loop.

Ans : **Comp 2019**

The magnitude of magnetic field induction (dB) at a point P due to a current element depends on the following factors.

1. $dB \propto I$ (i.e. magnetic field is directly proportional to the current flowing through the conductor).
2. $dB \propto dl$ (i.e. magnetic field is directly proportional to the length of the element).
3. $dB \propto \sin\theta$ (i.e. magnetic field is directly proportional to the sine of angle between the length of element and line joining the element to point (P).
4. $dB \propto \frac{1}{r^2}$ (i.e. magnetic field is inversely proportional to the square of distance between the element and point P). Combining all the above relations,

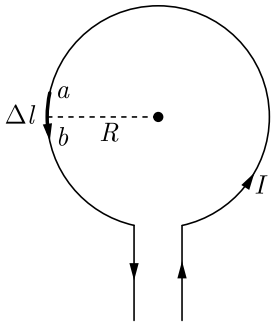
$$dB \propto \frac{Idl\sin\theta}{r^2}$$

The relation is called **Biot-Savart's law.**

Magnetic Field at the Centre of Circular Loop

Consider a circular coil of radius R carrying current I in anticlockwise direction. Say, O is the centre of coil, at which magnetic field is to be computed. The coil may be supposed to be formed of a large number of current elements. Consider a small current element ab of length Δl. According to Biot Savart law the magnetic field due to current element ab at centre O is,

$$dB = \frac{\mu_0}{4\pi}\frac{Idl\sin\theta}{R^2}$$



where, θ is angle between current element ab and the line joining the element to the centre O.Here $\theta = 90^\circ$, because current element at each point of circular path is perpendicular to the radius.

Therefore magnetic field produced at O, due to current element ab is,

$$dB = \frac{\mu_0}{4\pi}\frac{Idl}{R^2}$$

According to Maxwell's right hand rule, the direction of magnetic field at O is upward, perpendicular to the plane of coil. The direction of magnetic field due to all current elements is the same. Therefore the resultant magnetic field at the centre will be the sum of magnetic field due to all current elements.

Thus,
$$B = \int dB = \int \frac{\mu_0}{4\pi}\frac{Idl}{R^2}$$
$$= \frac{\mu_0}{4\pi}\frac{I}{R^2}\int dl$$

But,
$$\int dl = \text{total length of circuit coil}$$
$$= 2\pi R \text{ (for one-turn)}$$

Hence,
$$B = \frac{\mu_0}{4\pi}\frac{I}{R^2}.2\pi R$$

or
$$B = \frac{\mu_0 I}{2R}$$

If the coil contains N-turns, then

$$B = \frac{\mu_0 NI}{2R}$$

Here, current in the coil is anticlockwise and the direction of magnetic field is perpendicular to the plane of coil upward; but if the current in the coil is clockwise, then the direction of magnetic field will be perpendicular to the plane of coil downward.

150. Discuss the motion of a charged particle in a uniform magnetic field with initial velocity (1) parallel to the field, (2) perpendicular to the magnetic field and (3) at an arbitrary angle with the field direction.

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Ans : **Comp 2021**

When a charged particle having charge q and velocity $\vec{v}$ enters a magnetic field $\vec{B}$, it experiences a force,

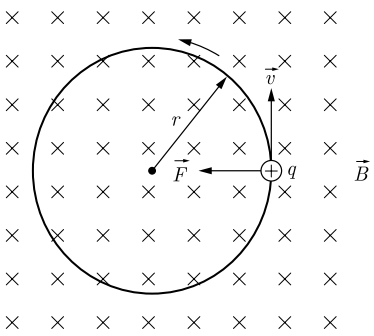
$$\vec{F} = q(\vec{v} \times \vec{B})$$

The direction of this force is perpendicular to both $\vec{v}$ and $\vec{B}$. The magnitude of this force is,

$$F = qvB \sin\theta$$

Following three cases are possible:

1. **When the Initial Velocity is Parallel to the Magnetic Field :** Here $\theta = 0^\circ$, so $F = qvB \sin 0^\circ = 0$. Thus the parallel magnetic field does not exert any force on the moving charged particle. The charged particle will continue to move along the line of force.
2. **When the Initial Velocity is Perpendicular to the Magnetic Field :** Figure shows a magnetic field $\vec{B}$ directed normally into the plane of paper, so shown by small crosses. A charge $+q$ is projected with a speed v in the plane of the paper. The velocity is perpendicular to the magnetic field. A force $F = qvB$ acts on the particle perpendicular to both $\vec{v}$ and $\vec{B}$. This force continuously deflects the particle sideways without changing its speed and the particle will move along a circle perpendicular to the field. Thus the magnetic force provides the centripetal force. Let r be the radius of the circular path.



Centripetal force,

$$\frac{mv^2}{r} = \text{Magnetic force, } qvB$$

$$r = \frac{mv}{qB}$$

Period of revolution,

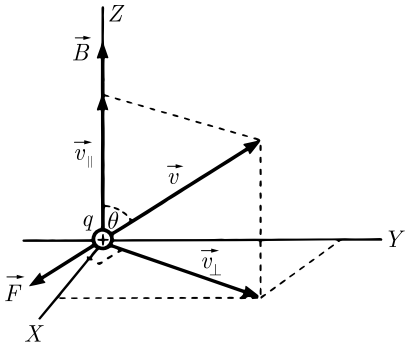
$$T = \frac{2\pi r}{v} = \frac{2\pi}{v} \cdot \frac{mv}{qB} = \frac{2\pi m}{qB}$$

The frequency of revolution is,

$$f_c = \frac{1}{T} = \frac{qB}{2\pi m}$$

This frequency is independent of v and r and is called cyclotron frequency.

3. **When the Initial Velocity Makes an Arbitrary Angle with the Field Direction :** Consider a charged particle q entering a uniform magnetic field $\vec{B}$ with velocity $\vec{v}$ inclined at an angle θ with the direction of $\vec{B}$.



The Perpendicular Component : $v_\perp = v \sin\theta$ of the initial velocity makes the charge move along a circular path of radius,

$$r = \frac{mv_\perp}{qB}$$

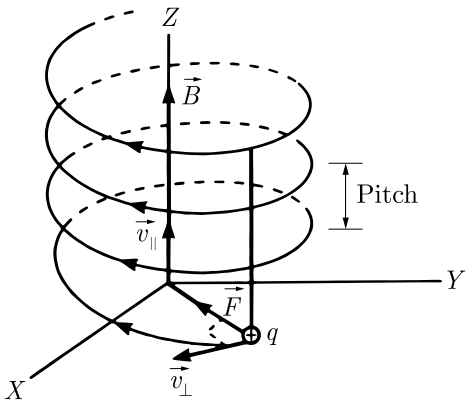
$$= \frac{mv \sin\theta}{qB}$$

The period of revolution is,

$$T = \frac{2\pi r}{v_\perp} = \frac{2\pi}{v \sin\theta} \cdot \frac{mv \sin\theta}{qB}$$

$$= \frac{2\pi m}{qB}$$

The Parallel Component : $v_\parallel = v \cos\theta$ of the initial velocity makes it move along the direction of the magnetic field. Hence the resultant path of the charged particle will be a helix, with its axis along the direction of $\vec{B}$.



Helical Motion of a Charged Particle in a Magnetic Field

NODIA

$$= 4\pi \times 10^{-7} \times (850 \times 5) \times 5/1$$
$$= 2.671 \times 10^{-2}\, T$$

Hence, Magnetic flux $= BA$

$$= 2.671 \times 10^{-2} \times \frac{22}{7} \times \left(\frac{3}{2} \times 10^{-2}\right)^2$$
$$= 1.89 \times 10^{-5}\, Wb$$

171. An electron having velocity $\vec{v} = 2\hat{i} + 3\hat{j}$ is projected into a uniform magnetic field $\vec{B} = 4\hat{k}$. Calculate the time period (T) of motion of the electron.

Ans : **Main 2020**

Given,

Velocity, $\vec{v} = 2\hat{i} + 3\hat{j}$

Magnetic field, $\vec{B} = 4\hat{k}$

Time period, $T = \dfrac{2\pi r}{v}$ ...(1)

Since, $v = \dfrac{eBr}{m_e}$ ...(2)

After substituting the value of Eq. (2) in Eq. (1), we get

Now, $T = \dfrac{2\pi m_e}{eB}$

Here, mass of electron,

$$m_e = 9.1 \times 10^{-31}\,\text{kg}$$

Hence, $T = \dfrac{2\pi m}{eB}$

$$= \frac{2 \times 3.14 \times 9.1 \times 10^{-31}}{1.6 \times 10^{-19} \times 4}$$
$$= 8.9 \times 10^{-12}\,\text{sec}$$

172. A magnetic field of 100 ($1\ \text{G} = 10^{-4}\ \text{T}$) is required which is uniform in a region of linear dimension about 10 cm and area of cross-section about $10^{-3}\,\text{m}^2$. The maximum current carrying capacity of a given coil of wire is 15 A and the number of turns per unit length that can be wound round a core is at most 1000 turns m^{-1}. Suggest some appropriate design particulars of a solenoid for the required purpose. Assume the core is not ferromagnetic.

Ans : **Main 2010**

Magnetic field, $B = 100$

$$G = 100 \times 10^{-4}\, T$$

The magnitude of magnetic field,

$$B = \mu_0 nI$$

or $$nI = \frac{10^{-2}}{4} \times 3.14 \times 10^{-7}$$
$$nI = 7961 \approx 8000$$

The product of nI is 8000.

Current, $I = 8$ A

Number of turns, $n = 1000$

The other design is,

$$I = 10\,\text{A}$$

and $$n = 800/\text{m}$$

This is the most appropriate design as per the requirement.

173. An electron of energy 2000 eV describes a circular path in magnetic field of flux density 0.2 T. What is the radius of path? Take, $e = 1.6 \times 10^{-19}\,\text{C}$, $m = 9 \times 10^{-31}\,\text{kg}$.

Ans : **Main 2017**

Here, energy of electron,

$$E' = 2000\,\text{eV}$$
$$E' = 2000 \times 1.6 \times 10^{-19}$$
$$J = 3.2 \times 10^{-16}\,\text{Joule}$$

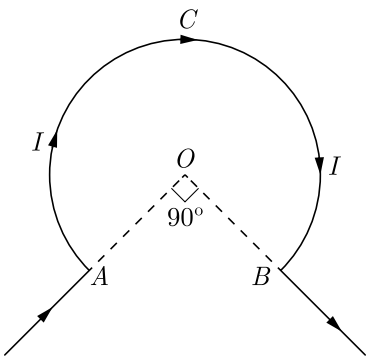
Now, $B = 0.2\,T$ $r = ?$

$$E' = \frac{1}{2}mv^2$$
$$v = \sqrt{\frac{2E'}{m}}$$
$$Bev = \frac{mv^2}{r}$$

Hence, $r = \dfrac{mv}{Be}$

$$= \frac{m}{Be}\sqrt{\frac{2E'}{m}} = \frac{\sqrt{2E'm}}{Be}$$
$$= \frac{\sqrt{2 \times 3.2 \times 10^{-16} \times 9 \times 10^{-31}}}{0.2 \times 1.6 \times 10^{-19}}$$
$$= 7.5 \times 10^{-4}\,\text{m}$$

174. The wire shown in the figure carries a current of 10 A. Determine the magnitude of magnetic field induction at the centre O. (Given the radius of the bent coil is 3 cm.)



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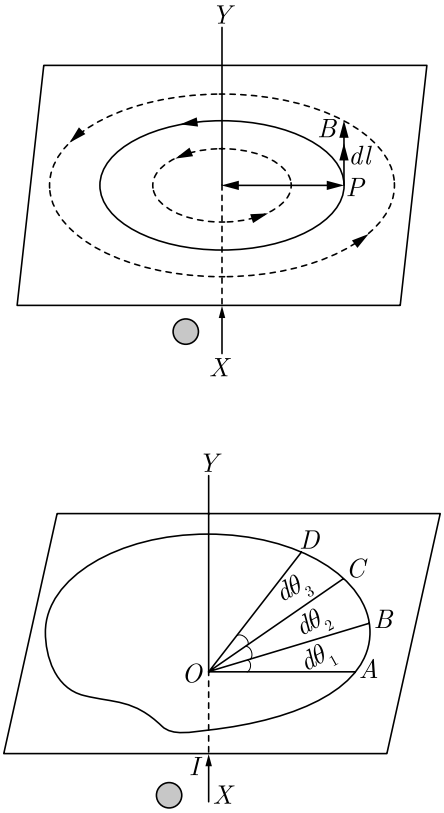
Ans : **Main 2004**

When current in the coil is in the anti-clockwise direction.



Consider any arbitrary closed path perpendicular to the plane of paper around a long straight conductor XY carrying current from X to Y, lying in the plane in the plane of paper.

Let, the closed path be made of large number of small elements, where

$$AB = dl_1,\ BC = dl_2,\ CD = dl_3$$

Let $d\theta_1, d\theta_2, d\theta_3$ be the angles subtended by the various elements at point O through which conductor is passing. Then,

$$d\theta_1 + d\theta_2 + d\theta_3 + \ldots = 2\pi$$

Suppose these small elements $AB, BC, CD, \ldots$ are small circular arcs of radii $r_1, r_2, r_3, \ldots$ respectively.

Then, $$d\theta_1 = \frac{dl_1}{r_1}$$

$$d\theta_2 = \frac{dl_2}{r_2},\ d\theta_3 = \frac{dl_3}{r^3}$$

If $\vec{B}_1, \vec{B}_2, \vec{B}_3$ are the magnetic field induction at a point along the small elements $\overrightarrow{dl_1}, \overrightarrow{dl_2}, \overrightarrow{dl_3}, \ldots$ then from Biot-Savart's law we know that for the conductor of infinite length, magnetic field is given by

$$B_1 = \frac{\mu_0}{4\pi}\frac{2I}{r_1}$$

$$B_2 = \frac{\mu_0}{4\pi}\frac{2I}{r_2}$$

$$B_3 = \frac{\mu_0}{4\pi}\frac{2I}{r_3} \ldots$$

In case of each elements, the magnetic field induction $\vec{B}$ and current element vector $\overrightarrow{dl}$ are in the same direction. Line integral of B around closed path is

$$\oint \vec{B} \cdot \overrightarrow{dl} = \vec{B}_1 \cdot \overrightarrow{dl_1} + \vec{B}_2 \cdot \overrightarrow{dl_2} + \vec{B}_3 \cdot \overrightarrow{dl_3} + \ldots$$

$$= B_1(dl_1) + B_2(dl_2) + B_3(dl_3) + \ldots$$

$$= \frac{\mu_0}{4\pi}\frac{2I}{r_1}dl_1 + \frac{\mu_0}{4\pi}\frac{2I}{r_2}dl_2 + \frac{\mu_0}{4\pi}\frac{2I}{r_3}dl_3 + \ldots$$

$$= \frac{\mu_0 2I}{4\pi}\left[\frac{dl_1}{r_1} + \frac{dl_2}{r_2} + \frac{dl_3}{r_3} + \ldots\right]$$

$$= \frac{\mu_0 2I}{4\pi}[d\theta_1 + d\theta_2 + d\theta_3 + \ldots]$$

$$= \frac{\mu_0}{4\pi} 2I \times 2\pi = \mu_0 I$$

$$\oint B \cdot dl = \mu_0 I$$

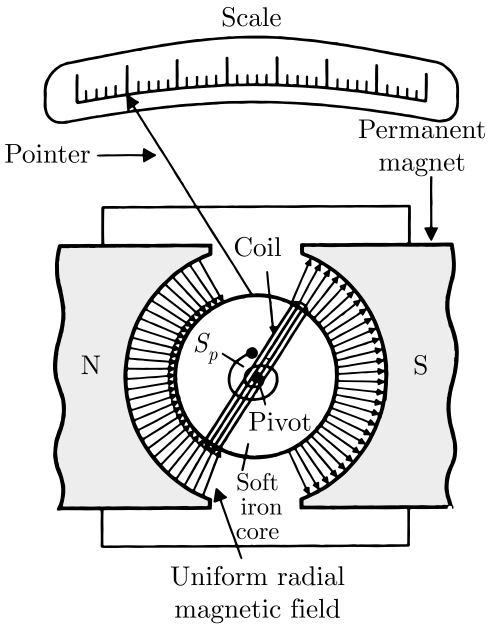
Which is an expression of Ampere's circuital law.

NODIA

153. Draw a labelled diagram of a moving coil galvanometer and explain its working. What is the function of radial magnetic field inside the coil ?

Ans : **SQP 2019, 2015**

Moving Coil Galvanometer Principle : Its working is based on the fact that when a current carrying coil is placed in a magnetic field, it experiences a net torque.



Length of the wire is same.

$$N_1 \times (2\pi R) = N_2 \times 2\pi\left(\frac{R}{2}\right)$$

[N_1 and N_2 = number of turns in two coils]

$$N_2 = 2N_1$$

Now, the ratio of magnetic moments is given by

$$\frac{M_1}{M_2} = \frac{N_1 I A_1}{N_2 I A_2} = \frac{N_1 \times \pi R_1^2}{N_2 \times \pi R_2^2}$$

$$\frac{M_1}{M_2} = \left(\frac{N_1}{2N_1}\right) \times \left(\frac{R}{R/2}\right)^2$$

$$= \frac{1}{2} \times 4 = 2$$

$$M_1 : M_2 = 1 : 2$$

162. A rectangular loop of area $5\,\text{m}^2$, has 50 turns and carries a current of 1 A. It is held in an uniform magnetic field of 0.1 T, at an angle of 30°. Calculate the torque experienced by the coil.

Ans : **Main 2019**

Given, area of rectangular loop,

$$A = 5\,\text{m}^2$$

Number of turns, $N = 50$

Current, $I = 1\,\text{A}$

Magnetic field, $B = 0.1\,\text{T}$

Angle, $\theta = 30^\circ$

Torque experienced by the coil,

$$\tau = NIAB\sin(90^\circ - \theta)$$

$$= 50 \times 1 \times 5 \times 0.1 \times \sin(90^\circ - 30^\circ)$$

$$= 50 \times 1 \times 5 \times 0.1 \times \sin 60^\circ$$

$$= \frac{25\sqrt{3}}{2} = 12.5\sqrt{3}\ \text{N-m}$$

163. A solenoid of length 50 cm having 100 turns carries a current of 2.5 A. Find the magnetic field (1) in the interior of the solenoid, (2) at one end of the solenoid.

Ans : **Main 2018**

Here, $I = 2.5\,\text{A}\ n = \frac{100}{0.50} = 200$

1. $B = \mu_0 nI$

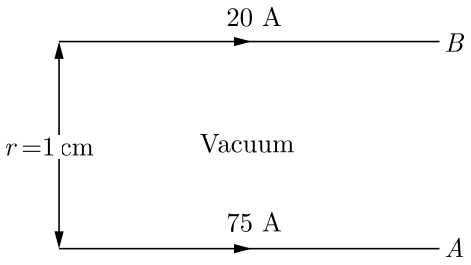
$$= 4\pi \times 10^{-7} \times 200 \times 2.5$$

$$B = 6.28 \times 10^{-4}\,T$$

2. $B = \frac{\mu_0 nI}{2} = \frac{4\pi \times 10^{-7} \times 200 \times 2.5}{2}$

$$= 3.14 \times 10^{-4}\,T$$

164. Calculate force per unit length acting on the wire B due to the current flowing in the wire A as shown in figure below.



Ans : **Main 2018**

Given, $i_1 = 20\,\text{A},\ i_2 = 75\,\text{A},$

$$r = 1\,\text{cm} = 1 \times 10^{-2}\,\text{m}$$

Force per unit length,

$$\frac{F}{l} = \frac{\mu_0}{2\pi} \cdot \frac{i_1 i_2}{r}$$

$$\frac{F}{l} = \frac{2 \times 10^{-7} \times 20 \times 75}{1 \times 10^{-2}}$$

$$\frac{F}{l} = 0.03\,\text{N/m}$$

165. A moving coil galvanometer has a coil of resistance $59\,\Omega$. It shows a full scale deflection for a current of 50 mA. How will you convert it to an ammeter having a range of 0 to 3 A?

Ans : **Main 2017**

Given,

$$R = 59\,\Omega$$

According to the formula,

$$S = \left(\frac{I_g}{I - I_g}\right) G$$

$$G = 59\,\Omega$$

$$I_g = 50\,\text{mA} = 50 \times 10^{-3}\,\text{A}$$

$$I = 3\,\text{A}$$

Shunt resistance

$$S = \frac{I_g G}{I - I_g} = \frac{50 \times 10^{-3} \times 59}{(3 - 50 \times 10^{-3})}$$

$$= \frac{50 \times 59}{1000 \times \frac{59}{20}} = \frac{50 \times 59 \times 20}{1000 \times 59} = 1\,\Omega$$

166. An element $dl = dx\hat{i}$ (where, $dx = 1\,\text{cm}$) is placed at the origin and carries a large current $I = 10\,\text{A}$. What is the magnetic field on the Y-axis at a distance of 0.5 m ?

Ans : **Main 2011**

Hence, $dl = dx = 1\,\text{cm} = 10^{-2}\,\text{m}$

$$I = 10\,\text{A}$$

$$r = 0.5\,\text{m}$$

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156. An electron moving with a velocity of $5 \times 10^7\ \text{ms}^{-1}$, enters in a magnetic field of $1\ \text{Wb m}^{-2}$ at an angle of 30°. Calculate the force on the electron.

Ans : **Main 2006, 2001**

Given,

Charge, $q = 1.6 \times 10^{-19}\ \text{C}$

velocity, $v = 5 \times 10^7\ \text{m/s}$

$\theta = 30^\circ,\ B = 1\ \text{Wbm}^{-2}$

$F = qvB\sin\theta$

$= 1.6 \times 10^{-19} \times 5 \times 10^7 \times 1 \times \sin 30^\circ$

$= 4 \times 10^{-12}\ \text{N}$

157. A moving coil galvanometer of resistance $55\,\Omega$ produces a full scale deflection for a current of 250 mA. How will you convert it into an ammeter having a range of 0 – 3 A?

Ans : **Main 2014**

$I_q = 250 \times 10^{-3}\ \text{A}$

$R_g = 55\,\Omega$

$I = 3\ \text{A}$

$R_s = ?$

$$R_s = \frac{I_g R_g}{I - I_g} = \frac{250 \times 10^{-3} \times 55}{3 - 250 \times 10^{-3}}$$

$$= \frac{250 \times 10^{-3} \times 55}{2.75}$$

$$= \frac{25 \times 55}{275} = 5$$

$R_s = 5\,\Omega$

To convert a galvanometer into an ammeter. Connect a $5\,\Omega$ resistance in parallel to it.

158. An electron moving with a velocity of $8 \times 10^6\ \text{m/s}$ enters a uniform and transverse magnetic field of $3 \times 10^{-3}\ \text{T}$. Calculate the radius of the circular path described by it.

Ans : **SQP 2009**

$m_e = 9 \times 10^{-31}\ \text{kg},\ v = 8 \times 10^6\ \text{m/s}$

$e = 1.6 \times 10^{-19}\ \text{C},\ B = 3 \times 10^{-3}\ \text{T}$

$$r = \frac{mv}{|e|B}$$

$$= \frac{(9 \times 10^{-31})(8 \times 10^6)}{(1.6 \times 10^{-19})(3 \times 10^{-3})}$$

$$= \frac{9 \times 10^{-31} \times 8 \times 10^{6+19+3}}{1.6 \times 3}$$

$= 1.5 \times 10^{-2}\ \text{m}$

159. A current of 5 A is flowing from South to North in a straight wire. Find the magnetic field due to a 1cm piece of wire at a point 1 m North-East from the piece of wire.

Ans : **SQP 2025**

Given, $I = 5$

$dl = 1\,\text{cm} = 0.01\,\text{m}$

$r = 1\,\text{m}$

$\theta = 45^\circ$

[Since, direction is North-East]

Hence, $$dB = \frac{\mu_0}{4\pi} \cdot \frac{Idl\sin\theta}{r^2}$$

$$= 10^{-7} \times \frac{5 \times 0.01 \times \sin 45^\circ}{(1)^2}$$

$= 3.54 \times 10^{-9}\,T$

Its direction is vertically downwards.

160. Find magnetic flux density at a point on the axis of a long solenoid having 5000 turns/m when it is carrying a current of 2 A.

Ans : **Comp 2014**

To find magnetic flux density at the centre of a solenoid, we have to find the magnetic field at the centre.

Magnetic flux density at the centre

= Magnetic field at the centre

$B = \mu_0 ni$

where, i = current through the solenoid

μ_0 = permeability of free space $= 4\pi \times 10^{-7}$

n = number of turns per unit length

$B = 4\pi \times 10^{-7} \times 5000 \times 2$

[$n = 5000$ turns/m, $i = 2$ A]

$= 8\pi \times 10^{-4} \times 5 = 4\pi \times 10^{-3}$

$= 1.256 \times 10^{-2}\ \text{T}$

161. A circular coil of N turns and radius R carries a current I. It is unwound and rewound to make another coil of radius $R/2$, current I remaining the same. Calculate the ratio of the magnetic moments of the new coil and the original coil.

Ans : **Main 2003**

The length of wire will be same in two cases as the same coil is unwound and rewound.

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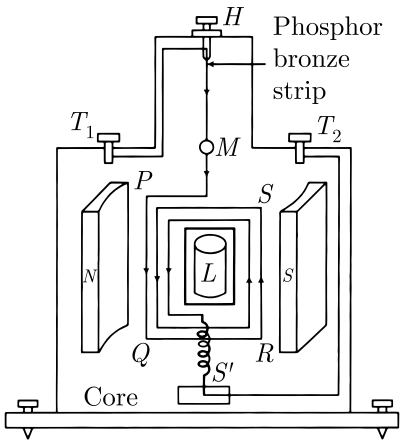


Working : Suppose, the coil $PQRS$ is suspended freely in the magnetic field.

Let l = length PQ or RS of the coil

b = breadth QR or SP of the coil

n = number of turns in the coil

Area of each turns of the coil, $A = l \times b$

Let $B =$ strength of the magnetic field in which coil is suspended.

$I =$ current passing through the coil in the direction of $PQRS$.

Let at any instant of time, α be the angle which normal drawn on the plane of the coil makes with the direction of magnetic field. The rectangular current carrying coil when placed in the magnetic field experiences a torque whose magnitude is given by $\tau = NIBA \sin\alpha$.

Due to this deflecting torque, the coil rotates and suspended wire gets twisted. A restoring torque is set up in the suspension wire.

Let θ be the twist produced in the phosphor bronze strip due to rotation of the coil and k be the restoring torque per unit twist of the phosphor bronze strip.

Then, total restoring torque produced $= k\theta$

In equilibrium position of the coil,

Deflecting torque = Restoring torque

$$NIBA = k\theta$$

or $$I = \frac{k}{NBA}\theta = G\theta$$

where, $$\frac{k}{NBA} = G$$

[constant for a galvanometer]

It is known as galvanometer constant.

Current sensitivity of the galvanometer is the deflection per unit current.

$$\frac{\phi}{I} = \frac{NAB}{k}$$

Voltage sensitivity is the deflection per unit voltage.

Hence, $$\frac{\phi}{V} = \frac{NAB}{k}\left(\frac{I}{V}\right)$$

$$= \frac{NAB}{k}\frac{1}{R} \quad [\text{since, } V = IR]$$

The uniform radial magnetic field keeps the plane of the coil always parallel to the direction of the magnetic field, i.e., the angle between the plane of the coil and the magnetic field is zero for all the orientations of the coil.

NUMERICAL QUESTIONS

NODIA

154. Calculate the magnetic field (in SI unit) at the centre of a tangent galvanometer coil of 50 turns and radius 10 cm when a current of 1.0 A passes through it.

Ans : **Main 2007**

Given, $N = 50,\ r = 10\,\text{cm} = 0.1\,\text{m},\ I = 1\,\text{A}$

Also, $\mu_0 = 4\pi \times 10^{-7}$

Magnetic field at the centre of tangent galvanometer is given by

$$B = \frac{\mu_0 NI}{2r}$$

So, $$B = \frac{4 \times 3.14 \times 10^{-7} \times 50 \times 1}{2 \times 0.1}$$

$$= 3.14 \times 10^{-4}\,\text{T}$$

155. A wire of length 10 cm, carrying 10 A of current is placed at an angle of 53° with respect to a magnetic field $\vec{B}$ of strength 0.1 T. Find the force experienced by the wire. [Use, sin 53°= 4/5]

Ans : **Main 2004**

Given, length of the wire,

$$l = 10\,\text{cm} = 0.1\ \text{m},$$

$$i = 10\,\text{A},\ \theta = 53^\circ,\ B = 0.1\,\text{T}$$

As $$F = iBl\sin\theta$$

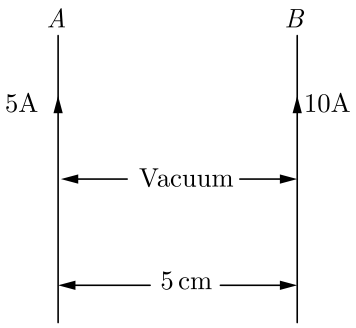
$$= 10 \times 0.1 \times 0.1 \times \sin 53^\circ$$

$$F = 0.08\,\text{N} \qquad \left[\sin 53^\circ = \frac{4}{5}\right]$$

Using Bio-Savart's law,

$$dB = \frac{\mu_0}{4\pi} \cdot \frac{Idl \times r}{r^3}$$
$$= \frac{\mu_0}{4\pi} \cdot \frac{Idx}{r^2}(\hat{i} \times \hat{j})$$
$$= \frac{\mu_0}{4\pi} \cdot \frac{Idx}{r^2}\hat{k} \qquad [\text{since } \hat{i} \times \hat{j} = \hat{k}]$$
$$= \frac{10^{-7} \times 10 \times 10^{-2}}{(0.5)^2}\hat{k}$$
$$= 4 \times 10^{-8}\hat{k}T$$

167. Two long straight wires A and B are kept parallel to each other, 5 cm apart, in vacuum. They carry currents of 5 A and 10 A respectively in the same direction as shown in figure below. Calculate the force per unit length acting on the wire B due to the current flowing in the wire A.



Ans : **SQP 2023**

Force per unit length between the wires

$$(F) = \frac{\mu_0 I_1 I_2}{2\pi d}$$
$$= \frac{4\pi \times 10^{-7} \times 5 \times 10}{2 \times \pi \times 5 \times 10^{-2}}$$
$$= 20 \times 10^{-5}$$
$$= 2 \times 10^{-4}\,\text{N/m}$$

168. A helium nucleus completes one round of a circle of radius 0.8 m is 2 s. Find the magnetic field at the centre of the circle.

Ans : **SQP 2017**

Magnetic field at the centre of a coil carrying current I is

$$B = \frac{\mu_0 NI}{2R}$$

In this case, revolving of helium nucleus will constitute the current.

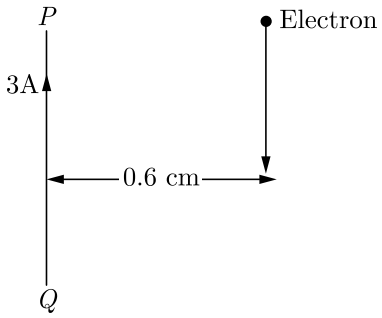
For $N = 1$, [i.e. only one turn]

$$B = \frac{\mu_0 \times N}{2R} \times \frac{2e}{t}$$

[For helium, $I = \frac{Q}{t} = \frac{2e}{t}$, as the nucleus has $+2e$ charge]

$$B = \frac{4\pi \times 10^{-7} \times 1 \times 2 \times 1.6 \times 10^{-19}}{2 \times 0.8 \times 2}$$
$$= 1.256 \times 10^{-25}\,\text{T}$$

169. PQ is a long straight conductor carrying a current of 3 A as shown in figure below. An electron moves with a velocity of $2 \times 10^7\,\text{ms}^{-1}$ parallel to it. Find the force acting on the electron.



Ans : **Main 2024**

We have to calculate force on a long straight conductor.

Force acting on the electron

$$F = qvB$$

Due to wire, the field created is

$$B = \frac{\mu_0 I}{2\pi R} = \frac{\mu_0 \times 3}{2 \times \pi \times 0.6}$$
$$= \frac{4\pi \times 10^{-7} \times 3 \times 10}{2 \times \pi \times 6} = 10^{-6}\,\text{T}$$

No, $F = 1.6 \times 10^{-19} \times 2 \times 10^7 \times 10^{-6}$

$$F = 32 \times 10^{-19}\,\text{N}$$

170. A solenoid of length 1.0 m and 3.0 cm diameter has 5 layers of windings of 850 turns each and carries a current of 5 A. What is the magnetic field at the centre of solenoid? Also, calculate the magnetic flux from a cross-section of the magnetic flux solenoid at the centre of solenoid.

Ans : **SQP 2013**

Number of turns,

$$N = 850 \times 5$$
$$l = 1\,\text{m}$$
$$I = 5\,\text{A}$$

Area of cross-section,

$$A = \pi r^2 = \frac{22}{7}\left(\frac{3}{2} \times 10^{-2}\right)^2\,\text{m}^2$$

Magnetic field at the center of solenoid,

$$B = \mu_0 NI/l$$

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The distance moved along the magnetic field in one rotation is called pitch of the helical path.

$$\text{Pitch} = v_{\parallel} \times T$$
$$= v\cos\theta \times \frac{2\pi m}{qB}$$
$$= \frac{2\pi m v\cos\theta}{qB}$$

151. Explain Biot-Savart law. With its help derive an expression for the magnetic field at any point on the axis of a current carrying circular loop.

Ans : **Main 2017**

According to Biot-Savart's law, the magnitude of magnetic field induction (dB) at a point P due to a current element depends on the following factors:

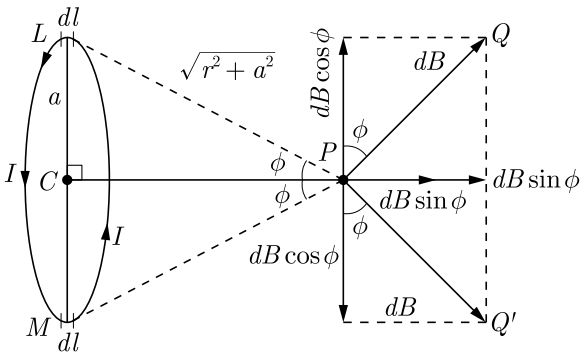
1. $dB \propto I$ (i.e., magnetic field is directly proportional to the current flowing through the conductor).
2. $dB \propto dl$ (i.e. magnetic field is directly proportional to the length of the element.)
3. $dB \propto \sin\theta$ (i.e., magnetic field is directly proportional to the sine of angle between the length of element and line joining the element to point, P).

Combining all the above relation $dB \propto \frac{Idl\sin\theta}{r^2}$

This relation is called Biot-Savart's law.

Magnetic Field on the Axis of a Circular Current Carrying Loop

Let us consider a circular loop of radius a with centre C. Let the plane of the coil be perpendicular to the plane of the paper and current I be flowing in the direction shown. Suppose P is any point on the axis of a coil at a distance r from the centre C.



Now, consider a current element Idl on top L, where current comes out of paper normally, whereas at bottom M, current enters into the plane paper normally.

Since, $LP \perp dl$

Also, $MP \perp dl$

Hence, $LP = MP = \sqrt{r^2+a^2}$

The magnetic field at a point P due to the current element Idl, according to Biot-Savart's law is given by,

$$dB = \frac{\mu_0}{4\pi}\cdot\frac{Idl\sin 90^\circ}{(r^2+a^2)}$$
$$= \frac{\mu_0}{4\pi}\cdot\frac{Idl}{(r^2+a^2)}$$

where, a = radius of circular loop

and r = distance of point P from the centre C along the axis.

According to right hand screw rule, the direction of dB is perpendicular to LP and along PQ, where $PQ \perp LP$. Similarly, the same magnitude of magnetic field is obtained due to current element Idl at the bottom and direction is along PQ', where $PQ' \perp MP$.

Now, resolving dB due to current element at L and M. So, $dB\cos\phi$ components balance each other and net magnetic field is given by,

$$B = \oint dB\sin\phi$$
$$= \oint \frac{\mu_0}{4\pi}\left(\frac{Idl}{r^2+a^2}\right)\cdot\frac{a}{\sqrt{r^2+a^2}}$$

$$\left[\text{Since, In } \Delta PCL, \sin\phi = \frac{a}{\sqrt{r^2+a^2}}\right]$$

$$= \frac{\mu_0}{4\pi}\frac{Ia}{(r^2+a^2)^{3/2}}\oint dl$$

$$\oint dl = \frac{\mu_0}{4\pi}\frac{Ia}{(r^2+a^2)^{3/2}}(2\pi a)$$

or $$B = \frac{\mu_0 Ia^2}{2(r^2+a^2)^{3/2}}$$

For N turns, the net magnetic field is given by,

$$B = \frac{\mu_0 NIa^2}{2(r^2+a^2)^{3/2}}$$

152. Explain how Biot-Savart law enables one to express the Ampere's circuital law in the integral form, viz.

$$\oint B\cdot dl = \mu_0 I$$

where, I is the total current passing through the surface.

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Ans : SQP 2019

Given, $I = 10\,\text{A}$

$r = 3\,\text{cm}$

$r = 3 \times 10^{-2}\,\text{m}$

$\theta = \frac{3\pi}{2}$ rad

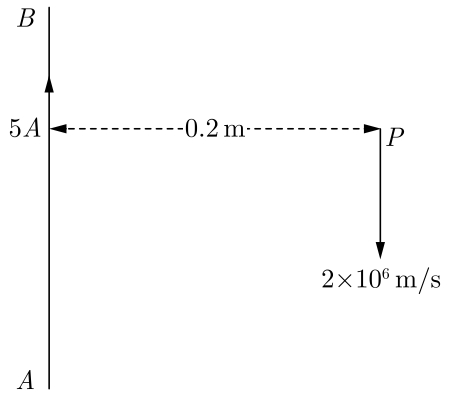
Magnetic field induction at O due to current through circular path ACB is,

$$B = \frac{\mu_0}{4\pi}\frac{I}{r}\theta$$

$$= 10^{-7} \times \frac{10}{(3 \times 10^{-2})} \times \frac{3\pi}{2}$$

$$= 1.57 \times 10^{-4}\,T$$

175. A long straight wire AB carries a current of 5 A. P is a proton travelling with a velocity of 2×10^6 m/s, parallel to the wire, 0.2 m from it and in a direction opposite to the current, as shown in figure below. Calculate the force which magnetic field of the current carrying conductor AB exerts on the proton.



Ans : Main 2023

Given,

$I = 5\,\text{A}$

$v = 2 \times 10^6\,\text{m/s}$

$r = 0.2\,\text{m}$

$$B = \frac{\mu_0}{4\pi}\frac{2I}{r} = \frac{10^{-7} \times 2 \times 5}{0.2}$$

$$= 5 \times 10^{-6}$$

Now,

$$\text{Force } (F) = qvB\sin 90^\circ$$

$$= (1.6 \times 10^{-19})(2 \times 10^6)(5 \times 10^{-6})$$

$$= 16 \times 10^{-19}$$

176. An Infinitely long straight current carrying wire, produces a magnetic field B, at a point distant a from it. What must be the radius of a circular loop, so that, for the same current through, it, the magnetic field at:

1. Its centre is equal to $B/2$?
2. An axial point, distance equal to the radius of the loop is equal to B?

Ans : Comp 2025

$$B = \frac{10^{-7} \times 2I}{a} = \frac{\mu_0 I}{2\pi a}$$

1. $$B_c = \frac{B}{2}$$

$$= \frac{10^{-7} \times 2I}{a \times 2}$$

$$= \frac{10^{-7} \times 2\pi l}{R}$$

$$R = 2\pi a$$

2. $$B_{\text{axis}} = \frac{\mu_0 I R^2}{2(x^2 + R^2)^{3/2}}$$

$$B = \frac{\mu_0 I}{2\pi a}$$

As, $x = R$

Hence, $$\frac{R^2}{(R^2 + R^2)^{3/2}} = \frac{1}{\pi a}$$

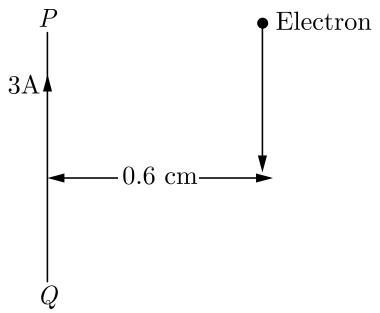
$$\frac{R^3}{2^{3/2} R^{2 \times 3/2}} = \frac{1}{\pi a}$$

$$\frac{R^2}{\sqrt{8R^3}} = \frac{1}{\pi a}$$

$$\frac{1}{\sqrt{8}} = \frac{R}{\pi a}$$

$$R = \frac{\pi a}{\sqrt{8}}$$

177. An electron is moving vertically upwards in the uniform magnetic field of the Earth. The velocity of the electron is 2.0×10^6 m/s and the horizontal component of the Earth's magnetic field is 0.32×10^{-4} T. Obtain the magnitude and direction of the force on the electron.



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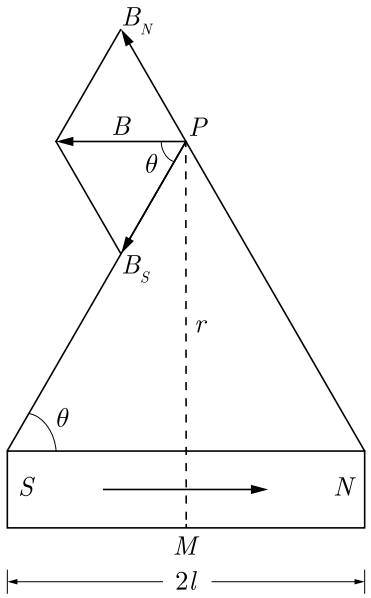
2. At on equatorial point (broadside-on-position)



$$\vec{B} = \frac{\mu_0}{4\pi} \cdot \frac{\vec{M}}{r^3}$$

The direction of magnetic field is parallel to the magnetic dipole and opposite to the direction of dipole moment.

8. MAGNETISM AND GAUSS' LAW

The net magnetic flux (φ_B) through any closed surface is always zero.

i.e., $$\varphi_B = \Sigma B \cdot \Delta S = 0$$

9. TERMS RELATED TO MAGNETIC PROPERTIES

Terms related to magnetic properties of material are given as below:

1. **Intensity of Magnetisation, I :** The magnetic dipole moment produced per unit volume field of specimen of magnetic material in magnetising field is known as intensity of magnetisation.

$$I = \frac{M}{V} = \frac{m}{A}$$

where, M = magnetic dipole moment,

m = pole strength,

v = volume of specimen

and A = cross-section area

2. **Magnetic Permeability :** It is equal to the ratio of magnetic induction and magnetising field.

$$\mu = \frac{B}{H}$$

3. **Magnetic Susceptibility :** It is equal to the ratio of intensity of magnetisation and magnetising field.

$$\chi_m = \frac{I}{H}$$

It has no unit.

10. MAGNETIC INDUCTION

It is defined as the number of magnetic lines of induction crossing per unit area through the magnetic substance.

$$B = \mu_0(H + I)$$

where, μ_0 = permeability of free space

H = magnetising field

I = intensity of magnetisation

11. CLASSIFICATION OF MAGNETIC MATERIALS

Magnetic materials may be classified into three categories

1. **Diamagnetic Substances :** These are the substances in which feeble magnetism is produced in a direction opposite to the applied magnetic field. These substances are repelled by a strong magnet. These substances have small negative values of susceptibility χ and positive low value of relative permeability μ_r, i.e.,

$$-1 \le \chi < 0 \text{ and } 0 \le \mu_r < 1$$

The examples of diamagnetic substances are bismuth, antimony, copper, lead, water, nitrogen (at STP) and sodium chloride.

2. **Paramagnetic Substances :** These are the substances in which feeble magnetism is induced in the same direction as the applied magnetic field. These are feebly attracted by a strong magnet. These substances have small positive values of M and χ and relative permeability μ_r greater than 1, i.e.,

$$0 < \chi < \varepsilon \text{ and } 1 < \mu_r < 1 + \varepsilon$$

Where ε is a small positive number. The examples of paramagnetic substances are platinum, aluminium, calcium, manganese, oxygen (at STP) and copper chloride.

3. **Ferromagnetic Substances :** These are the substances in which a strong magnetism is produced in the same direction as the applied magnetic field. These are strongly attracted by a magnet. These substances are characterised by large positive values of M and x and values of μ_r much greater than 1, i.e.,

$$\chi >> 1,\ \mu_r >> \chi$$

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3. At, $x = 2a$

$$B = \frac{\mu_0 I n a^2}{2(a^2 + 4a^2)^{3/2}}$$

$$= \frac{\mu_0 I n a^2}{2(5a^2)^{3/2}}$$

$$= \frac{\mu_0 I n}{2.5 \cdot \sqrt{5}a} = \frac{1}{5\sqrt{5}} B_0$$

$$= \frac{0.2\sqrt{5}}{\sqrt{5} \times \sqrt{5}} B_0$$

$$= 0.040 B_0 \approx 0.039 B_0$$

4. At, $x = 3a$

$$B = \frac{\mu_0 I n a^2}{2(a^2 + 9a^2)^{3/2}}$$

$$= \frac{\mu_0 I n a^2}{2(10a^2)^{3/2}} = \frac{\mu_0 I n}{2.10 \cdot \sqrt{10}\, a}$$

$$= \frac{B_0}{10\sqrt{10}} = \frac{\sqrt{10}\, B_0}{100}$$

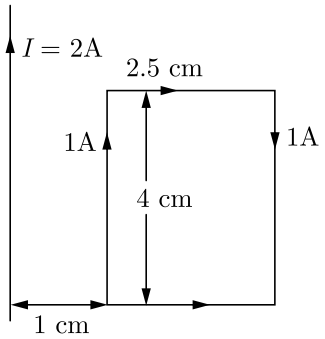
$$= 0.010\sqrt{10 B_0}$$

Hence, data are in good agreement for all values of x.

180. A rectangular loop of wire of size 2.5 cm × 4 cm carries steady current of 1 A. A straight wire carrying 2 A current is kept near the loop as shown. If the loop and the wire are coplanar, find the

(i) torque acting on the loop and

(ii) the magnitude and direction of the force on the loop due to the current carrying wire.



Ans : **Comp 2021**

There will be force of attraction between the straight wire and 4 cm long arm of loop nearer to the straight conductor.

$$F_1 = \frac{\mu_0}{4\pi} \frac{2 \times 2 \times 1}{(2 \times 10^{-2})} \times (4 \times 10^{-2})$$

[towards straight conductor]

$$F_1 = 8 \times 10^{-7}\,\text{N} \quad ...(1)$$

Similarly, force on other 4 cm arm of loop, away from the straight conductor.

$$F_2 = \frac{\mu_0}{4\pi} \times \frac{2 \times 2 \times 1}{(4.5 \times 10^{-2})} \times (4 \times 10^{-2})$$

$$F_2 = 3.55 \times 10^{-7}\,\text{N} \quad ...(2)$$

[away from conductor]

(i) Since, F_1 and F_2 are of different magnitudes, therefore, do not form couple and hence

Torque, $\tau = 0$

(ii) Net force on loop,

$$F = F_1 - F_2$$

[towards straight conductor]

$$F = 8 \times 10^{-7} - 3.55 \times 10^{-7}$$

$$F = 4.45 \times 10^{-7}\,\text{N}$$

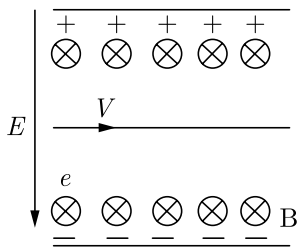
The forces on two branches of loop are equal in magnitude and opposite in the directions, hence they balance each other.

181. An electron beam passes through a region in which a magnetic field of 2×10^{-3} T and an electric field 3.4×10^4 V/m both acting simultaneously at right angles to each other. If the path of the electron remains undeflected, calculate the speed of the electrons. If the electric field is removed, what will be the radius of the circular path of electrons?

Ans : **Main 2002**

As the path of an electron remains undeflected, hence net force on the electron must be zero (balanced).

Consider the diagram, where an electron beam enters the region in which magnetic field (B) is perpendicularly inward ⊗ and electric field (E) is downward.



Force on electron due to electric field $= eE$ [upward] Force on electron due to magnetic field $= evB$

[downward]

[where, v = speed, e = electronic charge]

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For no deflection electric force will must be balanced by magnetic force

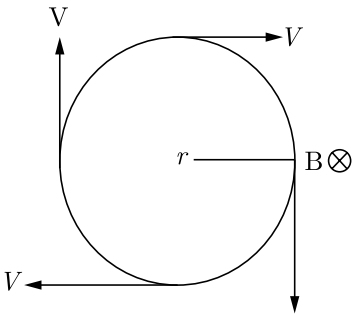
$$eE = evB$$

$$v = \frac{E}{B}$$

$$= \frac{3.4 \times 10^4}{2 \times 10^{-3}} \begin{bmatrix} \text{given, } E = 3.4 \times 10^4 \text{ V/m} \\ B = 2 \times 10^{-3} \text{ T} \end{bmatrix}$$

$$= 1.7 \times 10^7 \text{ m/s}$$

When electric field is removed, only magnetic field remains, hence path will be circular as shown in the figure.



Radius of the circular path (r) is given by

$$r = \frac{mv}{eB}$$

where, m is mass of the electron.

B is magnitude of the magnetic field

$$r = \frac{mv}{eB} = \frac{9.1 \times 10^{-31} \times 1.7 \times 10^7}{1.6 \times 10^{-19} \times 2 \times 10^{-3}}$$

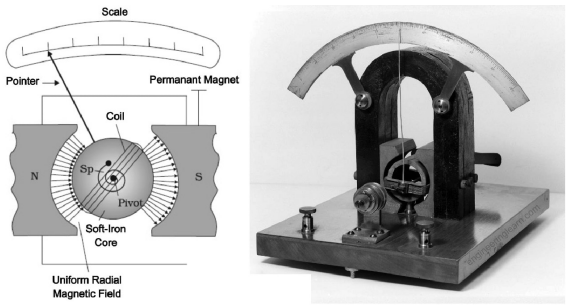
$$= 4.83 \times 10^{-31+29}$$

$$= 4.83 \times 10^{-2} \text{ m}$$

$$= 4.83 \text{ cm} \approx 5 \text{ cm}$$

CASE BASED QUESTIONS

182. Ajay and Sandeep were asked by their teacher to perform an experiment using a galvanometer. Before doing the experiment they were very keen to know the different parts of the galvanometer which was given to them in the form of a small box. They approached the teacher and asked for the permission. The teacher thought it would be a good idea if the galvanometer be opened before the whole class and explained its construction and working to all of them.



(a) State briefly the working principle of the galvanometer.

(b) What is the shape of the magnets used and why is it so designed ?

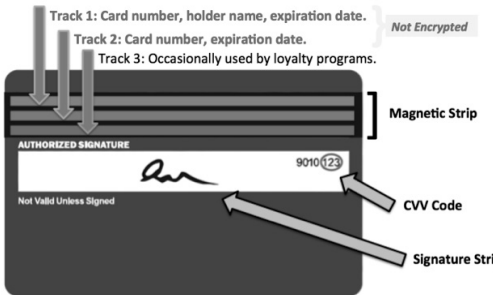
Ans : **2015**

(a) When current flows through a coil kept in uniform radial magnetic field, it experiences a torque which tends to rotate the coil and produces an angular deflection. The deflection of the coil is directly proportional to the current.

$$\theta = \frac{NAB}{K} \cdot I$$

(b) The shape of the magnets used is concave. It is designed to produce a radial magnetic field.

183. A credit card of an old villager was not working properly. Rakesh observed the card and found its stored data was corrupted due to mishandling of magnetic strip. He suggested him that brown strip on such card is a magnet. It carries a code which can be read by the cash dispenser machine. If you will mishandle such magnetic strip of it, then its stored data may become corrupted.



(a) How do magnetic strips work?

(b) A long wire carries a steady current. It is first bent into a circular loop and magnetic field at its centre is found to be B_0. Then the same wire is bent into a circular coil of n turns. Find the magnetic field at the centre point now.

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Ans : **2012**

(a) This standard tape strip contains three magnetic tracks that are used to store the card's code data. The card is usually presented to the reader by swiping or inserting it into the reader, which obtains the card's code using a magnetic head that detects the magnetic field generated by its strip.

(b) Let radius of circular loop be R, so the magnetic field at the centre,

$$B_0 = \frac{\mu_0 I}{2R} \quad ...(1)$$

In the second case, radius of the coil be r having n turns, then

$$2\pi r \cdot n = 2\pi R$$

$$r = \frac{R}{n}$$

Then, magnetic field at the centre of the coil,

$$B = \frac{n\mu_0 I}{2r} = \frac{n\mu_0 I}{2R/n} = \frac{n^2\mu_0 I}{2R}$$

$$= n^2 B_0 \text{ [From equation (1)]}$$

Thus, $B = n^2 B_0$

184. Deepak needed an ammeter of range 0 to 6 A for his project work. He went to physics laboratory and market for it. But it was not available to him. But a galvanometer of resistance of 15 Ω and its range of 0 to 4 mA was available in the laboratory, then he decided to convert such galvanometer into ammeter of given range.

(a) How does a ammeter work?

(b) How did he convert such galvanometer into ammeter of desired range ? Explain showing by calculations.

Ans : **2015**

(a) It is not mechanical, or digital. It uses an analog to digital converter (ADC) to measure the voltage across the shunt resistor. The ADC is read by a microcomputer that performs the calculations to display the current through the resistor.

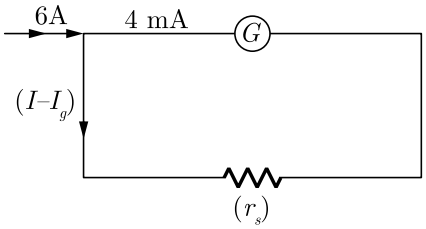
(b) Given, $R_G = 15\,\Omega$

$I_g = 4\,\text{mA} = 4 \times 10^{-3}\,\text{A}$

$I = 6\,\text{A}$

For converting galvanometer into ammeter of given range, We join a small shunt resistance r_s in parallel to the galvanometer.

$$I_g \times R_G = (I - I_g)\, r_g$$

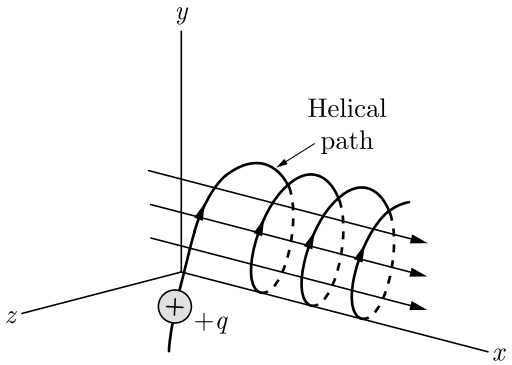


$$r_s = \frac{I_g}{I - I_g} \times R_G$$

$$= \frac{4 \times 10^{-3}}{6 - (4 \times 10^{-3})} \times 15$$

$$\approx 10^{-2}\,\Omega = 10\,\text{m}\Omega$$

185. If velocity has a component along B, this component remains unchanged as the motion along the magnetic field will not be affected by the magnetic field. The motion in a plane perpendicular to magnetic field is a circular one, thereby producing a helical motion.



1 What is the expression of radius of charged particle in the uniform magnetic field ?

2. An electron, proton, He^+ and Li^{++} are projected with the same velocity perpendicular to a uniform magnetic field. Which one will experience maximum magnetic force?

3. What is the work done by the magnetic field on the charge particle moving perpendicular to a uniform magnetic field?

4. How much distance moved by a charged particle along the magnetic field in one rotation, when velocity has a component parallel to magnetic field?

Ans : **2010**

1. R = mv/qB
2. Li^{++}
3. Zero
4. $\frac{2\pi mv\cos\theta}{qB}$

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the money. He convinced his uncle to undergo this test so as to enable the doctor to diagnose the disease. He got the test done and the resulting information greatly helped the doctor to give him proper treatment.

(a) Assuming that the MRI scan test involved a magnetic field of 0.1 T, find the maximum and minimum values of the force that this field could exert on a proton moving with a speed of $10^4\,\text{ms}^{-1}$. State the condition under which the force can be minimum.

(b) What is the principal mechanism for producing an MRI signal?

Ans : **2007**

(a) A strong magnetic field is required by using an expensive setup.

Magnetic force on moving charge particle in uniform magnetic field $\vec{B}$ can be given as

$$\vec{F} = q(\vec{v} \times \vec{B})$$

or $$|F| = qvB\sin\theta$$

(i) Maximum force at $\theta = 90^\circ$

$$F = qvB = 1.6 \times 10^{-19} \times 10^4 \times 0.1$$

$$= 1.6 \times 10^{-16}\,\text{N}$$

(ii) Minimum force at $\theta = 0^\circ$ and 180°

$$F = 0$$

i.e., charge particles either move parallel or anti-parallel to the magnetic field lines.

(b) Magnetic resonance imaging (MRI) uses the movement of protons within a magnetic field to generate an image. Within the constant magnetic field of an MRI scanner, tissues that contain free hydrogen nuclei (protons) generate varying signals when pulses of radio frequency (RF) energy are applied to them.

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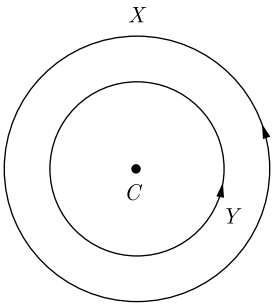

(i) Magnetic field at the common centre C due to current in the coil X is

(a) 7.5×10^{-4} T (b) 7.5×10^{-6} T

(c) 1.0×10^{-4} T (d) 2.0×10^{-4} T

(ii) Magnetic field at the common centre C due to current in the coil Y is

(a) 1×10^{-5} T (b) 2×10^{-4} T

(c) 2×10^{-3} T (d) 1×10^{-3} T

(iii) Resultant magnetic field at the common centre C due to the current in the coils X and Y is

(a) 2.5×10^{-3} T (b) 2.5×10^{-4} T

(c) 2.5×10^{-5} T (d) 2.5×10^{-6} T

Ans : **Main 2022 Sem-I**

Magnetic field at the centre of circular loop is

$$B = \frac{\mu_0 NI}{2R}$$

(i) (a) $$B_X = \frac{4\pi \times 10^{-7} \times 50 \times 6}{2 \times 8\pi \times 10^{-2}}$$
$$= 7.5 \times 10^{-4} \text{ T}$$

(ii) (b) $$B_Y = \frac{4\pi \times 10^{-7} \times 100 \times 2}{2 \times 4\pi \times 10^{-2}}$$
$$= 1 \times 10^{-3} \text{ T}$$

(iii) (b) $$B_{\text{net}} = B_Y - B_X$$
$$= (10 - 75) \times 10^{-4}$$
$$= 2.5 \times 10^{-4} \text{ T}$$

189. It is an easy and sensitive instrument to detect and measure electric current. Its action is based upon the principle that when electric current flows in a coil placed in a magnetic field, a deflecting torque acts upon the coil whose magnitude depends upon the strength of the current. From the measurement of the deflection of the coil, the strength of the current can be computed.

Moving-coil galvanometers are of two types: suspended-coil galvanometer and pivoted-coil (or Weston) galvanometer. The principle and working of the two types of galvanometers are the same, only there is some difference in their constructions. In suspended-coil galvanometer, the coil is suspended by a thin phosphor-bronze strip and the deflection of the coil is measured by a lamp and scale arrangement. In pivoted-coil galvanometer, the coil swings between two pivots and the deflection of the coil is read by a pointer on a circular scale. The pivoted-coil galvanometer is less sensitive than the suspended-coil galvanometer, but can be taken easily from one place to another.

(i) What do you mean by moving coil galvanometer ?

(ii) On which principle the moving coil galvanometer is based on?

(iii) Write the types of moving coil galvanometer.

(iv) What are the difference between the types of galvanometer?

(v) From the suspended coil galvanometer and the pivoted-coil galvanometer. Which galvanometer is more sensitive?

Ans : **2009**

(i) Moving-coil galvanometer is an easy and sensitive instrument to detect and measure electric current.

(ii) Moving-coil galvanometer is based upon the principle that when electric current flows in a coil placed in a magnetic field, a deflecting torque acts upon the coil whose magnitude depends upon the strength of the current.

(iii) Moving coil galvanometer are of two types:

(a) Uspended-coil galvanometer

(b) Pivoted-coil (or Weston) galvanometer

(iv) In suspended-coil galvanometer, the coil is suspended by a thin phosphor-bronze strip and the deflection of the coil is measured by a lamp and scale arrangement and pivoted-coil galvanometer, the coil swing between two pivots and the deflection of the coil is read by pointer on a circular scale.

(v) Pivoted coil galvanometer is less sensitive than suspended coil galvanometer.

190. Rahul's uncle was advised by his doctor to undergo an MRI scan test of his chest who also gave him an estimate of the cost. Not knowing much about the significance of this test and finding it to be too expensive he first hesitated. When Rahul learnt about this, he decided to take help of his family, friends and neighbours and arranged for

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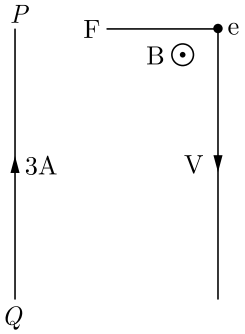
Ans : **Main 2000**

The force on a charged particle moving in a magnetic field $\vec{B}$ with velocity $\vec{v}$ and having charge q is $q(\vec{v} \times \vec{B})$.



The magnitude of force is

$$|\vec{F}| = q|\vec{v}||\vec{B}|\sin\theta$$

where, q = charge

v = speed of the charged particle

B = magnitude of the magnetic field

θ = angle between $\vec{v}$ and $\vec{B}$

$$\vec{F} = q(\vec{v} \times \vec{B}) = -e(\vec{v} \times \vec{B})$$

From the figure we can observe that the force will act towards the wire.

$$|\vec{F}| = evB \qquad [\theta = 90^\circ]$$
$$= 1.6 \times 10^{-19} \times 2 \times 10^{6} \times 0.32 \times 10^{-4}$$
$$= 1.024 \times 10^{-17}\ \text{N}$$

178. An ammeter of resistance $0.80\,\Omega$ can measure current upto 1.0 A.

1. What must be the value of shunt resistance to enable the ammeter to measure current upto 5.0 A?
2. What is the combined resistance of the ammeter and the shunt?

Ans : **SQP 2020**

Given,

Resistance of ammeter,

$$R_A = 0.80\,\Omega$$

Maximum current across ammeter,

$$I_A = 1.0\,\text{A}$$

So, voltage across ammeter,

$$V = IR = 1.0 \times 0.80 = 0.8\,\text{V}$$

Let the value of shunt is x.

1. Resistance of ammeter with shunt,

$$R = \frac{R_A x}{R_A + x} = \frac{0.8x}{0.8 + x}$$

Current through ammeter,

$$I = 5\,\text{A}$$
$$\left(\frac{0.8x}{0.8 + x}\right) \times 5 = 0.8$$
$$0.8x \times 5 = 0.8(0.8 + x)$$
$$4x = 0.64 + 0.8x$$
$$x = \frac{0.64}{3.2} = 0.2$$

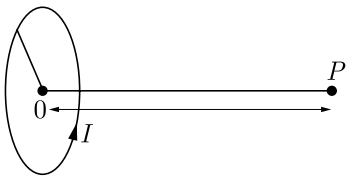
So, the shunt resistance is 0.2 ohm.

2. Combined resistance of the ammeter and the shunt,

$$R = \frac{0.8x}{0.8 + x} = \frac{0.8 \times 0.2}{0.8 + 0.2}$$
$$= \frac{0.16}{1} = 0.16\,\Omega$$

179. A student records the following data for the magnitudes (B) of the magnetic field at axial points at different distance x from the centre of a circular coil of radius a carrying a current. Verify (for any two) that these observations are in good agreement with the expected theoretical variation of B with x.

x	$x = 0$	$x = a$	$x = 2a$	$x = 3a$
B	B_0	$0.25\sqrt{2B_0}$	$0.039\sqrt{5B_0}$	$0.010\sqrt{10B_0}$



Ans : **Main 2019**

We have,

Magnetic field at axial point,

$$B = \frac{\mu_0 I n a^2}{2(a^2 + x^2)^{3/2}}$$

1. At, $x = 0$

$$B_0 = \frac{\mu_0 I n}{2a}$$

2. At, $x = a$

$$B = \frac{\mu_0 I n a^2}{2(a^2 + a^2)^{3/2}} = \frac{\mu_0 I n a^2}{2(2a^2)^{3/2}}$$
$$= \frac{\mu_0 n I}{2^{5/2} a} = \frac{B_0}{2^{5/2}}$$
$$= \frac{B_0}{2^2 \cdot 2^{1/2}} = 0.25\sqrt{2}\,B_0$$

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CHAPTER 5

Magnetism and Matter

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SUMMARY

1. MAGNETIC FIELD LINES

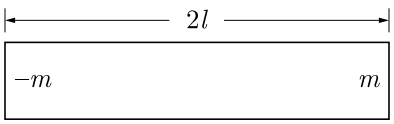
These are imaginary lines which give pictorial representation for the magnetic field inside and around the magnet.

Properties of electric field lines are given as below:

1. These lines form continuous closed loops.
2. The tangent to the field line gives direction of the field at that point.
3. Larger the density of the lines, stronger will be the magnetic field.
4. These line do not intersect each other.

2. MAGNETIC DIPOLE MOMENT OF A CURRENT LOOP AND REVOLVING ELECTRON

Magnetic dipole moment of a magnet, $M = m \times 2l$ A-m^2.



Where m is a pole strength, $2l$ is separation between poles.

Magnetic dipole moment of a current loop,

$$M = NIA \text{ A-m}^2$$

The direction of m is perpendicular of the plane of loop and given by right hand thumb rule.

Magnetic dipole moment of a revolving electron

$$= IA = e\nu\pi r^2$$

where ν is frequency, r is radius of orbit.

$$M = \frac{e}{2m_e}L \text{ A-m}^2$$

Here $L = m_e vr$ is angular momentum of revolving electron.

3. BAR MAGNET AS AN EQUIVALENT SOLENOID

The expression of magnetic field at distance r from the centre is given by,

$$\vec{B} = \frac{\mu_0}{4\pi} \cdot \frac{2\vec{M}}{r^3}$$

This expression is equivalent to that of bar magnet.

4. TORQUE OF BAR MAGNET

Torque on a bar magnet in a uniform magnetic field is,

$$\tau = MB\sin\theta = M \times B$$

where, θ is the angle between M and B. Its S.I. units is joule per tesla (JT^{-1}).

5. POTENTIAL ENERGY OF A MAGNETIC DIPOLE

Potential energy of a magnetic dipole in a magnetic field is given by,

$$U = -MB\sin\theta = -M \times B$$

where, θ is the angle between M and B.

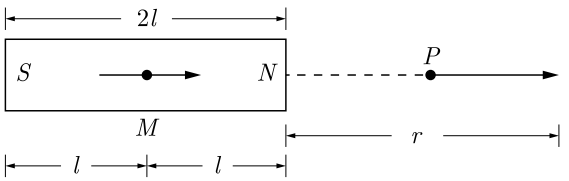
6. WORD DONE IN ROTATING THE DIPOLE

Work done in rotating the dipole in a uniform magnetic field from θ_1 to θ_2 is given by

$$W = MB(\cos\theta_1 - \cos\theta_2)$$

7. MAGNETIC FIELD DUE TO A BAR MAGNET

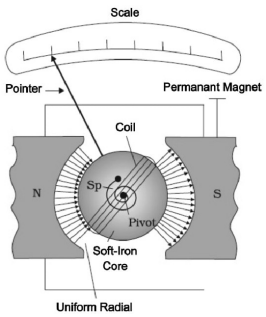
1. At an axial point (end-on-position).

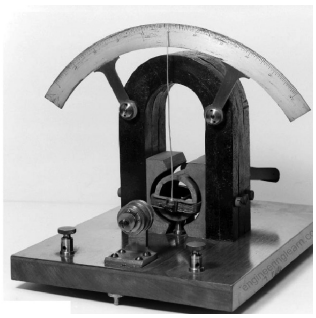


$$\vec{B} = \frac{\mu_0}{4\pi} \cdot \frac{2\vec{M}}{r^3} \quad (\text{Since } r >> l)$$

The direction of magnetic field is along the direction of magnetic dipole moment M.

186. The galvanometer is a device used to detect the current flowing in a circuit or a small potential difference applied to it consists of a coil with many turns, free to rotate about a fixed axis, in a uniform radial magnetic field formed by using concave pole pieces of a magnet. When a current flow through the coil, a torque acts on it.





1 What is the principle of moving coil galvanometer?

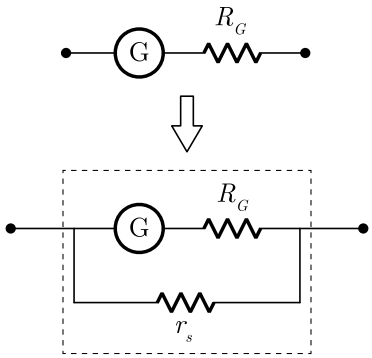
2. If the field is radial, what is the angle between magnetic moment of galvanometer coil and the magnetic field?

3. Why pole pieces are made concave in the moving coil galvanometer?

Ans : **2008**

1. A current-carrying coil when placed in an external magnetic field experiences magnetic torque. The angle through which the coil is deflected due to the effect of the magnetic torque is proportional to the magnitude of current in the coil.
2. 30°
3. The pole pieces of the galvanometer are made concave so that the current-carrying coil and the magnetic field are always perpendicular to each other. Concave magnetic pole always produces a radial magnetic field. The radial field will always be perpendicular to the conductor rotating about the axis.

187. The galvanometer cannot be used as an ammeter to measure the value of the current directly as it is a very sensitive device. It gives a full-scale deflection for current of the order of μA. For measuring currents, the galvanometer has to be connected in series, and as it has a large resistance, this will change the value of current in the circuit.



Ammeter

1 How is a moving coil galvanometer converted into an ammeter of desired range?

2. A moving coil galvanometer of resistance G gives a full-scale deflection for a current I_g. It is converted into an ammeter of range 0- I ampere. What should be the value of shunt resistance to convert it into an ammeter of desired range?

3 Which one will have the greatest resistance – a micro-ammeter, a milli-ammeter, an ammeter?

4 What is the resistance of ammeter?

Ans : **2015**

1 Connecting a shunt resistance in parallel.

2. $S = \dfrac{IG}{I - I_g}$

3 Micro-ammeter

4 $\dfrac{1}{R_A} = \dfrac{1}{G} + \dfrac{1}{S}$

188. X and Y are two concentric and coplanar circular coils carrying currents of 6 A and 2 A in opposite directions as shown in figure below. Their radii are $R_X = 8\pi$ cm and $R_Y = 4\pi$ cm, whereas number of turns in X and Y are 50 and 100, respectively.

Answer the following on basis of above information.

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OBJECTIVE QUESTIONS

1. SI unit of magnetic dipole moment is

(a) A-m (b) A-m^2

(c) Hm^{-1} (b) Wbm^{-2}

Ans : **Main 2022 Sem-I**

The magnetic dipole moment of a current loop is given by m = I·A, where I is current (in amperes) and A is the area (in m^2). So the unit becomes A-m^2 . Thus (b) is correct option.

2. If a material, placed in a magnetic field is thrown out of it, then the material is

(a) diamagnetic (b) paramagnetic

(c) ferromagnetic (d) non-magnetic

Ans : **SQP 2005**

Diamagnetic materials are repelled when they are placed in a magnetic field. That is why, diamagnetic material is thrown out if it.

Thus (a) is correct option.

3. A super conductor exhibits perfect

(a) ferrimagnetism (b) ferromagnetism

(c) paramagnetism (d) diamagnetism

Ans : **Main 2011, 2010**

a substance with permeability less than unity is called diamagnetic. Since the superconductor has a zero permeability, therefore it exhibits perfect diamagnetism.

Thus (d) is correct option.

4. Which of the following is an example for diamagnetic substances?

(a) copper (b) nickel

(c) aluminium (d) iron

Ans : **Main 2008**

Copper is an example of diamagnetic substance. And nickel, aluminium, iron are substances.

Thus (a) is correct option.

5. The direction of null points are on the equatorial line of a bar magnet, when the north pole of the magnet is pointing towards

(a) north (b) south

(c) east (d) west

Ans : **Main 2012**

When the north pole of a bar magnet is pointing towards north direction, then magnetic lines of force pass through the magnet.

Thus (a) is correct option.

6. Magnetic susceptibility of platinum is 0.0001. Its relative permeability is

(a) 1.0000 (b) 0.9999

(c) 1.0001 (d) 0

Ans : **Main 2017**

Magnetic susceptibility of platinum

$$\chi_m = 0.0001$$

Relative permeability

$$\mu_r = 1 + \chi_m = 1 + 0.0001 = 1.0001$$

Thus (c) is correct option.

7. S.I. unit of magnetic moment is

(a) JT^{-2} (b) Am^2

(c) JT (d) Am^{-1}

Ans : **Main 2025**

The magnetic moment of a magnetic dipole is defined as the product of its pole strength and magnetic length, $2l$ i.e.,

$$M = m \times 2l$$

SI unit of magnetic moment is ampere-$meter^2$(Am^2).

Thus (b) is correct option.

8. S.I. unit of pole strength is

(a) N (b) $N/A - m$

(c) $A - m$ (d) T

Ans : **Main 2017, 2010**

Magnetic dipole moment

$$= \text{Pole strength} \times \text{Length}$$

$$\text{Pole strength} = \frac{\text{Magnetic dipole moment}}{\text{length}}$$

$$= \frac{A - m^2}{m}$$

$$= A - m$$

Thus (c) is correct option.

9. Metals getting magnetised by orientation of atomic magnetic moments in external magnetic field are called

(a) diamagnetics (b) paramagnetics

(c) ferromagnetics (d) anti-magnetics

Ans : **Comp 2011**

those metals which are magnetised by orientation of atomic magnetic moments in external magnetic field are called paramagnetics.

Thus (b) is correct option.

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24. A frog can be levitated in magnetic field produced by a current in a vertical solenoid placed below the frog. This is possible because the body of the frog behaves as

(a) paramagnetic

(b) diamagnetic

(c) ferromagnetic

(d) anti-ferromagnetic

Ans : SQP 2013

when diamagnetised materials are placed in a magnetic field, they are feebly magnetised in the opposite direction of the magnetising field or repelled. Since the frog levitated in magnetic field produced by a current in vertical solenoid placed below the frog due to repulsion, therefore body of the frog behaves as diamagnetic.

Thus (b) is correct option.

25. The domain formation is a necessary feature of

(a) diamagnetism (b) paramagnetism

(c) ferromagnetism (d) all of these

Ans : SQP 2024

a ferromagnetic substance is composed of tiny crystals-like regions. And within each crystal there are one or more domains. And in each domain, there is a perfect alignment of the elementary moment represented by an arrow. That is why domain, there is a perfect alignment of the elementary moment represented by an arrow. That is why, domain formation is a necessary feature of ferromagnetism.

Thus (c) is correct option.

26. Substances which are strongly attracted by magnetic field i.e., move from weaker to stronger side of the field are termed as

(a) diamagnetic substances

(b) paramagnetic substances

(c) ferromagnetic substances

(d) non-magnetic substances

Ans : Main 2006

Ferromagnetic substances are strongly magnetised in the direction of magnetising field. Therefore ferromagnetic substances move from weaker to stronger side of the magnetic field.Thus (c) is correct option.

27. If χ_{m_1} and χ_{m_2} are the susceptibilities of a diamagnetic substance at temperatures T_1 and T_2 respectively, then

(a) $\chi_{m_1} = \chi_{m_2}$

(b) $\chi_{m_1} T_1 = \chi_{m_2} T_2$

(c) $\chi_{m_1} T_2 = \chi_{m_2} T_1$

(d) $\chi_{m_1} \sqrt{T_1} = \chi_{m_2} \sqrt{T_2}$

Ans : Main 2016

Given,

Initial susceptibility, $T_1 = \chi_{m_1}$

Final susceptibility, $T_2 = \chi_{m_2}$

Susceptibility of a diamagnetic substance is independent of temperature. And it does not obey Curie's law.

Therefore, $\chi_{m_1} = \chi_{m_2}$

Thus (a) is correct option.

28. The vertical component of the earth's magnetic field is zero at a place where the angle is dip is

(a) $0°$ (b) $45°$

(c) $60°$ (d) $90°$

Ans : Main 2001

Vertical component of earth's magnetic field,

$$B_V = 0$$

Vertical component of the earth's magnetic field at a place,

$$B_V = B\sin\delta$$

Therefore, If $B_V = 0$, Then

$$\sin\delta = 0$$

(where, δ is Angle of dip)

$$\delta = 0$$

Thus (a) is correct option.

29. When the intensity of magnetic field is increased four times, the time period of suspended magnetic needle becomes

(a) double (b) half

(c) four times (d) one-fourth less

Ans : Main 2016

The time period of suspended magnetic needed is given by,

$$T = 2\pi\sqrt{\frac{I}{mB}}$$

i.e., $$T \propto \frac{1}{\sqrt{B}}$$

Hence, $$\frac{T_1}{T_2} = \sqrt{\frac{B_2}{B_1}}$$

$$\frac{T_1}{T_2} = \sqrt{\frac{4B_1}{B_1}}$$

$$T_2 = \frac{T_1}{2}$$

The time period of suspended magnetic needed becomes half. Thus (b) is correct option.

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Ans : **Main 2018**

The magnetic dipole moment represents the strength and direction of a magnet. It is a vector quantity directed from the south pole to the north pole of the magnet. This direction is chosen by convention and helps describe the magnetic field produced by the magnet in space.

Thus (a) is correct option.

18. Magnetic lines of force

(a) always intersect.

(b) are always closed.

(c) do not pass through vacuum.

(d) tend to crowd far way from the poles of a magnet.

Ans : **SQP 2009**

Outside the magnet, magnetic lines of force travel from north to south-pole, whereas inside the magnet, these lines, travel from south to north-pole.That is why, the magnet lines of force are always closed.

Thus (b) is correct option.

19. Susceptibility of a magnetic substance is found to depend on temperature and the strength of the magnetising field. The material is a

(a) diamagnet (b) ferromagnet

(c) paramagnet (d) superconductor

Ans : **SQP 2010**

Ferromagnetism of a substance decreases with the rise in temperature. Moreover, a ferromagnetic substance gets strongly magnetised along the direction of the magnetic field. Therefore the material is ferromagnet.

Thus (b) is correct option.

20. The magnetic lines of force inside a bar magnet

(a) do not exist

(b) are from north-pole to south-pole of the magnet

(c) are from south-pole to north-pole of the magnet

(d) depend upon the area of cross-section of the bar magnet

Ans : **Main 2025**

Magnetic lines of force, due to a bar magnet, from a closed loop and outside the bar magnet, these lines from north-pole to south-pole, whereas inside the bar magnet, these lines travel from south-pole to north-pole of the magnet.

Thus (c) is correct option.

21. Permeability μ of a ferromagnetic substance

(a) $\mu >> 1$ (b) $\mu = 1$

(c) $\mu < 1$ (d) $\mu = 0$

Ans : **Main 2015**

The magnetic permeability μ of a magnetic substance gives the ratio of the magnetic flux density in the material B to the intensity of external magnetising field H in which it is placed.

Thus, We have

$$\mu = \frac{B}{H}$$

A ferromagnetic substance is strongly magnetised in the direction of the external magnetising field. Thus B is very larger than H. Therefore, its permeability μ is enormously greater than one i.e. $\mu >> 1$.

Thus (a) is correct option.

22. If a bar magnet is dropped down in an infinitely long vertical copper tube, then the magnet will move continuously

(a) increasing velocity and acceleration.

(b) increasing velocity but constant acceleration.

(c) decreasing velocity and ultimately comes to rest.

(d) increasing velocity and ultimately acquires a constant terminal velocity.

Ans : **Main 2001**

When a bar magnet is dropped down in an infinitely long vertical copper tube, its velocity continuously increases due to the gravitational attraction. As a result of this, the velocity of bar magnet continuously goes on increasing but having constant acceleration due to free fall under gravity.

Thus (b) is correct option.

23. At which place, the earth's magnetism becomes horizontal?

(a) magnetic pole

(b) geographical pole

(c) magnetic equator

(d) magnetic meridian

Ans : **SQP 2018**

Magnetic field of the earth becomes horizontal at a place where angle of magnetic dip is zero.

Since, the angle of magnetic dip at magnetic meridian is zero, therefore earth's magnetism becomes horizontal at that place.

Thus (d) is correct option.

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47. Relative permeability of a material $\mu_r = 0.5$. identify the nature of the magnetic material and write its relation of magnetic susceptibility.

Ans : Main 2014

The nature of magnetic material is a diamagnetic.

$$\mu_r = 1 + \chi_m$$

48. Where on the earth's surface is the value of vertical component of earth's magnetic field zero?

Ans : Main 2018

Vertical component of earth's magnetic field is zero at magnetic equator.

49. Define Curie temperature.

Ans : SQP 2024

Curie temperature (T_C) is the temperature at which certain materials lose their ferromagnetic property to become paramagnetic.

50. The Susceptibility of a magnetic material is 1.9×10^{-5}. Name the type of magnetic material it represents.

Ans : Main 2011

The small and positive susceptibility of 1.9×10^{-5} represents paramagnetic substance.

51. Which of the following substances are diamagnetic?

Bi, Al, Cu, Ca, and Ni

Ans : SQP 2019

Diamagnetic substances are

(i) Bi,

(ii) Cu.

52. State the SI unit of the magnetic moment of a magnet, indicating its direction.

Ans : Main 2006

SI unit of the magnetic moment is A-m^{2}It is directed along the axis of dipole from South-pole to North-pole.

53. Explain the term hysteresis.

Ans : Main 2015

The phenomenon of lagging of flux density (dB) behind the magnetising force (H) in a ferromagnetic material subjected to cycles of magnetisation is known as hysteresis.

54. What are permanent magnets ?

Ans : SQP 2013

Substances that retain their attractive property for a long period of time at room temperature are called permanent magnets.

55. Why is the core of an electromagnet made of ferromagnetic materials?

Ans : Main 2010

Ferromagnetic material has a high retentive. So on passing current thorough windings it gains suffice magnetism immediately.

56. Why is soft iron preferred to steel in making the core of a transformer?

Ans : SQP 2018

Soft iron is used to make core of transformer because hysteresis loop of soft iron is narrow than steel, therefore energy loss is small.

57. At a certain temperature, a ferromagnetic material becomes paramagnetic. What is the temperature called?

Ans : Main 2025

At a temperature known as Curie temperature ferromagnetic material becomes paramagnetic.

58. State how the magnetic susceptibility of a ferromagnetic material changes when it is heated.

Ans : Main 2009

The magnetic susceptibility (χ) of a ferromagnetic substance varies with temperature as

$$\chi \propto \frac{1}{T - T_C} \qquad [T > T_C]$$

59. A magnetic needle, free to rotate in a vertical plane, orients itself vertically at a certain place on the Earth. What are the values of (i) horizontal component of Earth's magnetic field and (ii) angle of dip at this

Ans : Comp 2020

(i) 0°, (ii) 90°

60. The horizontal component of the earth's magnetic filed at a place is B and angle of dip is 60° what is the value of vertical component of earth's magnetic field at equator?

Ans : Main 2021

On the equator,the values of both angles of dip (δ) and vertical component of earth's magnetic field is zero. So, in the this case, $B_V = 0$.

61. State how magnetic susceptibility is different for the three types of magnetic materials, i.e. diamagnetic, paramagnetic and ferromagnetic materials.

Ans : Main 2015

For diamagnetic material, susceptibility is less than 0. For paramagnetic material, susceptibility is more than zero but less than 1.

Ferromagnetic material has very high value in positive.

NODIA

30. In $\tan A$ and $\tan B$ positions of a magnet the magnet fields at a distance d are represented by B_1 and B_2 respectively, then

(a) $B_1 = \frac{\mu_0}{4\pi} \cdot \frac{2Md}{(d^2 - l^2)^2}$, $B_2 = \frac{\mu_0}{4\pi} \cdot \frac{M}{(d^2 + l^2)^{3/2}}$

(b) $B_1 = B_2$; $d >> 1$

(c) $B_1 = 2B_2$; $d >> 1$

(d) Both a and c

Ans : **Main 2009**

According to the deflection magnetometer, the magnetic field in $\tan A$ and $\tan B$ position is given by,

$$B_1 = \frac{\mu_0}{4\pi} \cdot \frac{2Md}{(d^2 - l^2)^2} \quad \text{(for } \tan A \text{ position)}$$

$$B_2 = \frac{\mu_0}{4\pi} \cdot \frac{M}{(d^2 + l^2)^{3/2}} \quad \text{(for } \tan B \text{ position)}$$

If $d >> l$ then,

$$B_1 = \frac{\mu_0}{4\pi} \cdot \frac{2m}{d^3}$$

and

$$B_2 = \frac{\mu_0}{4\pi} \cdot \frac{M}{d^3}$$

$$\frac{B_1}{B_2} = 2$$

$$B_1 = 2B_2$$

$$d >>> 1$$

Thus (d) is correct option.

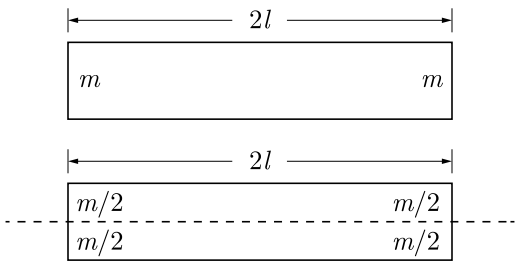
31. A bar magnet of magnetic moment M is cut into two parts of equal length. The magnetic moment of either part is

(a) M (b) $M/2$

(c) $2M$ (d) Zero

Ans : **Main 2018**

If a bar magnet of magnetic moment M is cut into two parts as shown in figure,



Dipole moment, $M = m \times 2l$ ...(1)

When bar magnet is cut into two parts of equal length. Then,

Dipole moment, $M' = m/2 \times 2l$

$$= \frac{1}{2} \times (m \times 2l)$$

From Eq. (1), we get

$$M' = \frac{M}{2}$$

Thus (b) is correct option.

32. A wire of magnetic dipole moment M and L is bent into shape of a semicircle of radius r. What will be its new dipole moments?

(a) M (b) $\frac{M}{2\pi}$

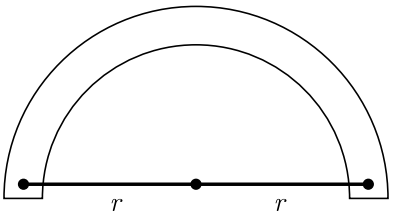
(c) $\frac{M}{\pi}$ (d) $\frac{2M}{\pi}$

Ans : **Main 2018**

As per the given question

Magnetic dipole moment of wire is given by,

$$M = m \times L \quad ...(1)$$



Now, Circumference of semicircle

= length of the wire

$$\pi r = L$$

$$r = \frac{L}{\pi} \quad ...(2)$$

Magnetic dipole moment of semicircle is given by,

$$M' = m \times 2r$$

$$M' = m \times 2 \times \frac{L}{\pi} \quad \text{From Eq.(2)}$$

$$= \frac{m \times 2L}{\pi}$$

$$M' = \frac{2M}{\pi} \quad \text{From Eq.(1)}$$

Thus (d) is correct option.

ASSERTION AND REASON

33. **Assertion (A) :** Diamagnetic substances exhibit magnetism.

Reason (R) : Diamagnetic materials do not have permanent magnetic dipole moment.

(a) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).

(b) Both Assertion (A) and Reason (R) are true and Reason (R) is not the correct explanation of Assertion (A).

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10. Liquid oxygen remains suspended between two poles of a magnet, because it is

(a) diamagnetic

(b) paramagnetic

(c) ferromagnetic

(d) anti-ferromagnetic

Ans : **Main 2016, 2009**

The liquid oxygen (O_2) is paramagnetic, because each oxygen molecule has two unpaired electrons. This is why, it remains suspended between two poles of the magnet.

Thus (b) is correct option.

11. Most of the substance show which of the following magnetic property?

(a) diamagnetism (b) paramagnetism

(c) ferromagnetism (d) both (b) and (c)

Ans : **Main 2024**

all substances show diamagnetism, as it is universal. Since both the paramagnetism and ferromagnetism in substances have diamagnetism in weak, therefore they are hard to detect.

Thus (a) is correct option.

12. A diamagnetic material in a magnetic field moves

(a) from weaker to stronger parts.

(b) perpendicular to the field.

(c) from stronger to weaker parts.

(d) in none of the above directions.

Ans : **SQP 2010**

Diamagnetic materials are magnetised in the opposite direction of the magnetising field. Therefore diamagnetic material moves from stronger to weaker parts of the magnetic field.

Thus (c) is correct option.

13. The magnetic field at a distance r from a short bar magnet is directly proportional to

(a) r^2 (b) r^{-3}

(c) $r^{2/3}$ (d) r^4

Ans : **SQP 2013**

magnetic field due to a short bar magnet at a distance r from itself,

$$B = \frac{\mu_0 M}{4\pi r^3} \propto r^{-3}$$

where, M = Magnetic moment of magnet

Thus (b) is correct option.

14. At the magnetic poles of the earth, a campus needle will be

(a) vertical

(b) horizontal

(c) inclined at 10° with the vertical.

(d) inclined at 45° with the horizontal.

Ans : **Main 2011, 2007**

horizontal component of earth's magnetic field at the magnetic poles of the earth is zero.

Therefore, a compass needle at this place will be vertical.

Thus (a) is correct option.

15. If a diamagnetic substance is brought near north or south pole of a bar magnet, then it is

(a) attracted by the poles

(b) repelled by the poles

(c) attracted by the north pole and repelled by the south pole

(d) repelled by the north pole and attracted by the south pole

Ans : **Main 2002**

When diamagnetic substances are magnetised in the opposite direction of the magnetising field. That is why, when a diamagnetic substance is brought near the north or south pole of a bar magnet, it is repelled by the poles.

Thus (b) is correct option.

16. The magnetic susceptibility does not depend upon the temperature in

(a) ferrite substances

(b) ferromagnetic substances

(c) diamagnetic substances

(d) paramagnetic substances

Ans : **Comp 2016**

Susceptibility of diamagnetic substances is constant and has low negative value (-10^{-6} to -10^{-7}). It does not depend upon the temperature.

Thus (c) is correct option.

17. Magnetic dipole moment is a vector quantity directed from

(a) South to North Pole

(b) North to South Pole

(c) East to West direction

(d) West to East direction

NODIA

the susceptibility of ferromagnetic substance varies inversely with its absolute temperature. Ferromagnetic substance obeys Curie's law only above its Curie point.

Thus (c) is correct option.

39. **Assertion :** The ferromagnetic substance do not obey Curie's law.

Reason : At Curie point a ferromagnetic substance start behaving as a paramagnetic substance.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **Main 2012**

The susceptibility of ferromagnetic substance decreases with the rise of temperature in a complicated manner. After Curie point in the susceptibility of ferromagnetic substance varies inversely with its absolute temperature. Ferromagnetic substance obeys Curie's law only above its Curies point.

Thus (b) is correct option.

40. **Assertion :** A paramagnetic sample display greater magnetisation (for the same magnetic field) when cooled.

Reason : The magnetisation does not depend on temperature.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **SQP 2011**

A paramagnetic sample display greater magnetisation when cooled, this is because at lower temperature, the tendency to disrupt the alignment of dipoles (due to magnetising field) decreases on account of reduced random thermal motion.

Thus (d) is correct option.

41. **Assertion :** The poles of magnet can not be separated by breaking into two pieces.

Reason : The magnetic moment will be reduced to half when a magnet is broken into two equal pieces.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **Main 2010**

When a magnet is cut into pieces, each piece becomes new magnet.

$$M' = \frac{ml}{2} = \frac{M}{2}$$

Thus (b) is correct option.

ONE MARK QUESTIONS

42. State the SI unit of magnetic dipole moment.

Ans : **Main 2013**

SI unit of magnetic dipole moment is A-m^2.

43. Where on the earth's surface is the value of angle of dip maximum?

Ans : **Main 2020**

Angle of dip (90°) is maximum at magnetic poles

44. *A* small magnet is pivoted to move freely is the magnetic meridian. At what place on earth's surface will the magnet be vertical?

Ans : **SQP 2020, 2013**

Magnet will be vertical at magnetic pole of the earth.

45. The Susceptibility of a magnetic material is -4.2×10^{-6}. Name the type of magnetic material it represents.

Ans : **Main 2025**

Negative susceptibility represents diamagnetic substance.

46. The permeability of a magnetic material is 0.9983. Name the type of magnetic materials it represents.

Ans : **Comp 2018**

$\mu_r < 1$, so magnetic material is diamagnetic.

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(c) Assertion (A) is true and Reason (R) is false.

(d) Assertion (A) is false and Reason (R) is also false.

Ans : **Main 2023, 2014**

Diamagnetic material exhibits magnetism in reverse direction and due to the absence of unpaired electron in diamagnetic material it does not exhibit permanent magnetic dipole moment.

Thus (b) is correct option.

34. **Assertion :** We cannot think of a magnetic field configuration with three poles.

Reason : A bar magnet does exert a torque on itself due to its own field.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **SQP 2018**

Magnet field may be formed with the help of three poles. A bar magnet does not exert a torque on itself due to its own field.

Thus (d) is correct option.

35. **Assertion :** Diamagnetic materials can exhibit magnetism.

Reason : Diamagnetic materials have permanent magnetic dipole moment.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **Main 2014**

Diamagnetic material exhibits magnetism in reverse direction. Reason is a wrong statement. Because due to absence of unpaired electron in diamagnetic material it does not exhibit permanent magnet dipole moment.

Thus (c) is correct option.

36. **Assertion :** Ferro-magnetic substances become paramagnetic above Curie temperature.

Reason : Domains are destroyed at high temperature.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **SQP 2013**

Susceptibility of ferro magnets decreases with increase of temperature. At a transition temperature is increased, dipoles acquire kinetic energy and are disoriented, hence domain internal interaction called exchange coupling disappears.

Thus (a) is correct option.

37. **Assertion :** Magnetic Resonance Imaging (MRI) is a useful diagnostic tool for producing images of various parts of human body.

Reason : Protons of various tissues of the human body play a role in MRI.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **Main 2014**

MRI is useful diagnostic tool for producing images of various parts of human body because it makes use of magnetic property of spinning proton inside the nucleus.Thus (a) is correct option.

38. **Assertion :** The ferromagnetic substance do not obey Curie's law.

Reason : At Curie point a ferromagnetic substance start behaving as a paramagnetic substance.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **SQP 2012**

The susceptibility of ferromagnetic substance decreases with the rise of temperature in a complicated manner. After Curies point in

62. Two substances A and B have their relative permeabilities slightly greater and slightly less than 1 respectively. What do you conclude about A and B as far as their magnetic materials are concerned?

Ans : **Main 2014**

For paramagnetic substances $\mu_r > 1$ and for diamagnetic substances $\mu_r < 1$, where μ_r is relative permeability. Thus, A is paramagnetic and B is diamagnetic material.

63. Arrange the three types of magnetic materials i.e. paramagnetic, diamagnetic and ferromagnetic materials, in decreasing order of their magnetic susceptibility.

Ans : **Main 2010, 2003**

For ferromagnetic materials, χ_m is very high.

For paramagnetic materials, χ_m is positive.

For diamagnetic materials, χ_m is negative.

So, decreasing order of magnetic susceptibility is ferromagnetic, paramagnetic and diamagnetic.

64. Explain the term of Curie temperature.

Ans : **SPQ 2018**

The magnetic susceptibility of these substances decreases on increasing the temperature and above a particular temperature, a ferromagnetic substance behaves like a paramagnetic substance. This particular temperature is called the Curie temperature T_C of the substance.

65. What is the importance of radial magnetic field in a moving coil galvanometer?

Ans : **SQP 2014**

1. The plane of the coil remains parallel to the direction of magnetic field. So, the galvanometer is linear.
2. It is a stronger magnetic field as compared to the magnetic field produced by the flat pieces of a field magnet.

66. The relative magnetic permeability of a magnetic material is 800. Identify the nature of magnetic material and state its two properties.

Ans : **SQP 2018**

Ferromagnetic substances, as these substances have very high magnetic permeability.

Properties :

1. High retentivity.
2. High susceptibility.

67. Magnetic field lines show the direction (at every point) along which a small magnetised needle aligns (at the point). Do the magnetic field lines also represent the 'lines of force'?

Ans : **Main 2012**

No, the magnetic field lines certainly represent the direction of magnetic field, but not the direction of force; this is because force is always perpendicular to magnetic field $\vec{B}$. Therefore, it is misleading to call magnetic field lines as the lines of force.

68. Magnetic field lines can be entirely confined with the core of toroid, but not within a straight solenoid, why?

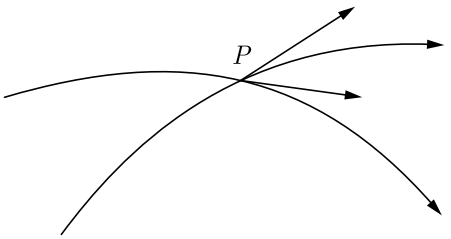
Ans : **Main 2017, 2011**

The field lines cannot be entirely confined to the two ends of a straight solenoid. If they were so, the magnetic flux through the cross-section at each end would have been non-zero; this is denied by Gauss theorem of magnetism. For a toroid, this difficulty does not arise because it is endless.

69. Why cannot two magnetic lines of forces due to a bar magnet cross each other?

Ans : **Comp 2017, 2013**

Two magnetic field lines cannot cross each other because at any point(say P) , the magnetic field has only one definite direction. If two field lines crossed, it would mean the magnetic field at that point has two different directions simultaneously, which is impossible. Therefore, magnetic lines of force never intersect.



TWO MARKS QUESTIONS

70. How does a diamagnetic material behave when it is cooled to very low temperature?

Ans : **Main 2014**

For diamagnetic substances, the variation of susceptibility is very small, i.e., diamagnetic materials are unaffected by the change in temperature (except bismuth).

71. Why does a paramagnetic sample display greater magnetisation when cooled? Explain.

Ans : **Main 2017**

A paramagnetic sample displays greater tendency when cooled at lower temperatures, the tendency

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to disrupt the alignment of magnetic dipole decreases due to the reduced random thermal motion of atoms or molecules.

72. An iron bar is heated to 1000° C and then cooled in a magnetic field free space. Will it retain magnetism?

Ans : SQP 2025, 2007

The iron bar will lose its magnetism as the temperature to which it is heated (i.e. 1000° C) is much above the curie point for iron (i.e. 770° C). So the iron bar magnet after heating to 1000° C and then cooled, cannot retain its magnetism.

73. Distinguish between diamagnetic and paramagnetic substances in terms of its relative permeability (μ_r) and magnetic susceptibility (χ)

Ans : Main 2005

Property	Diamagnetic	Paramagnetic
Relative permeability (μ_r)	$\mu_r < 1$	$\mu_r > 1$
Magnetic susceptibility (χ)	Low and negative	Low and positive

74. Out of the two magnetic materials, A has relative permeability slightly greater than unity while B has less than unity. Identify the nature of the materials A and B. Will their susceptibilities be positive or negative?

Ans : SQP 2017

The nature of the material A is paramagnetic and its susceptibility χ_m is positive.

The nature of the material B is diamagnetic and its susceptibility χ_m is negative.

75. The motion of copper plate is damped when it is allowed to oscillate between the two poles of a magnet. What is the cause of this damping?

Ans : Comp 2018, 2009

As the copper plates oscillate in the magnetic field between the two plates of the magnet, there is a continuous change of magnetic flux linked with the pendulum. Due to this, eddy currents are set up in the copper plate which try to oppose the motion of the pendulum according to the Lenz's law and finally bring it to rest.

76. A short bar magnet, placed with its axis making an angle θ with a uniform magnetic field $\vec{B}$, experiences a torque $\vec{\tau}$. What is the magnetic moment of the magnet?

Ans : SQP 2017

The torque $\vec{\tau}$ experienced by a bar magnet placed in a uniform magnetic field $\vec{B}$ is given by,

$$\vec{\tau} = \vec{M} \times \vec{B}$$

In magnitude, $\tau = MB \sin\theta$

$$M = \frac{\tau}{B \sin\theta}$$

77. A magnetic needle is placed on a cork floating on a still lake in the northern hemisphere. Does this needle together with the cork move towards the north of the lake?

Ans : SQP 2015

Since magnetic needle does not experience any net force, so the needle and the cork will not move towards the north of the lake. But, if the needle is inclined to the magnetic meridian, a torque will act on the needle and after a few oscillations, the needle will set itself along the magnetic meridian.

78. Why does paramagnetic substance move from weaker to stronger parts of non-uniform magnetic field?

Ans : Main 2018

The atoms of paramagnetic substances posses permanent magnetic dipoles and these dipoles are randomly distributed in the absence of external magnetic field. But when the paramagnetic substance is subjected to a non-uniform magnetic field, each atom experiences a torque tendency to align its magnetic dipole moment along the direction of magnetic field, and thus a paramagnetic substance moves from weaker to stronger magnetic field.

79. A magnetic needle suspended freely in uniform magnetic field experiences a torque but no net force. An iron nail near a bar magnet however experiences a force of attraction in addition to torque. Why?

Ans : SQP 2024

When a magnetic needle is suspended freely in uniform magnetic field, the two poles of the needle will experience equal and opposite forces hence net force is zero. On the other hand, when an iron nail is placed near a bar magnet, the magnetic field of bar magnet is non-uniform and the two poles of the iron nail will experience different force.

80. What is meant by a paramagnetic substance? State Curie's law.

Ans : Main 2011

These substances (paramagnetic) when placed in a magnetic field, acquire feeble magnetism in the direction of the magnetic field.

Curie's law Susceptibility (χ) of a paramagnetic substance varies inversely with absolute temperature of the substance.

i.e. $\chi \propto \frac{1}{T}$

81. Why does a magnetic dipole possess potential energy, when placed at some inclination with the direction of the field?

Ans : **Comp 2017**

When a magnetic dipole if placed in a uniform magnetic field, it aligns itself along the direction of the magnetic field in equilibrium. If a magnetic dipole is displaced from equilibrium position, a restoring torque acts on the dipole which bring it back. So if a dipole is placed at some inclination with the field, work has to be done against the restoring force. This work done is stored in the form of potential energy in the magnetic dipole.

82. Why does a paramagnetic sample displays greater magnetism when cooled?

Ans : **Main 2014**

The paramagnetic material contains atoms possessing permanent magnetic dipole moment. When a paramagnetic material is placed in a magnetic field, these magnetic dipoles get aligned in the direction of magnetic field. The high temperature disrupt this alignment. When a paramagnetic material is cooled, the thermal agitation trying to disrupt the alignment decreases and thus sample displays greater magnetism.

83. What is the basic difference between magnetic and electric lines of force?

Ans : **SQP 2011, 2006**

The basic difference between magnetic and electric lines of force is that whereas magnetic lines of force are closed continuous curves, the electric lines of force are discontinuous. They start from the positive charge and end at the negative charge. On the contrary, magnetic lines of force exist even inside the body of the magnet and are therefore closed continuous curves.

84. Obtain the dimensions and units of magnetic dipole moment.

Ans : **Main 2009**

For any current loop,Magnetic dipole moment

$$= \text{Current} \times \text{Area of the loop}$$

Hence, $[m] = [A][L^2] = [AL^2]$

SI unit of magnetic dipole moment is Am^2. It is defined as the magnetic moment associated with one turn loop of area one square metre when a current of one ampere flows through it.

85. State two characteristic properties distinguishing behaviour of paramagnetic and diamagnetic materials.

Ans : **Comp 2021**

The dereference between distinguishing and paramagnetic Substance are as follows :

Diamagnetic Substance	**Paramagnetic Substance**
In non-uniform magnetic field, the diamagnetic substances are attracted towards the weaker field, i.e., they move from stronger to weaker magnetic field.	In non-uniform magnetic field, paramagnetic substances move from weaker to stronger part of the magnetic field slowly.
Their permeability is less then one $(\mu < 1)$.	Their permeability is lightly greater than one $(\mu > 1)$.

NODIA

86. Write two differences between electromagnet and permanent magnet.

Ans : **Main 2020**

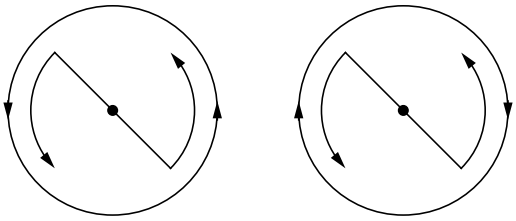
The difference between electromagnet and permanent magnet are as follows :

	Electromagnet	**Permanent Magnet**
1.	It shows temporary magnetism. It produces the magnetic field as long as currents flows in its coil.	It shows permanent magnetism i.e., it retain magnetism in it even when the current is switched off.
2.	The polarity of a electromagnet can be changed by reversing the direction of the current.	The polarity of a permanent magnet cannot be changed.

87. How does a circular loop carrying current behaves as a magnet?

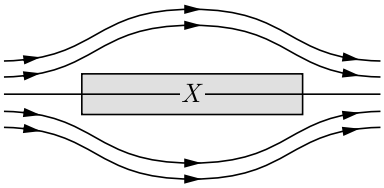
Ans : **Main 2011**

The current round in the face of the coil is in anti-clockwise direction, then this behaves like a North pole, whereas when it viewed from other scale, then current round in it is in clockwise direction necessarily forming South pole of magnet.

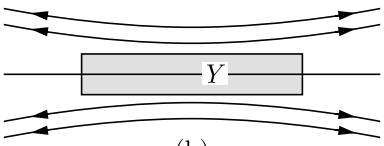


Hence, current loop have both magnetic poles and therefore, behaves like a magnetic dipole.

88. A uniform magnetic field gets modified as shown in the figure, when two specimens X and Y are placed in it.



(a)



(b)

Ans : Comp 2019

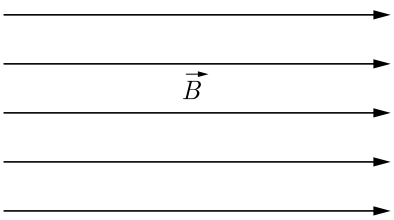
1. X-is a diamagnetic substance because in these substance, the magnetic field lines are farther than in air.
2. Y-is a ferromagnetic substance because in these substance the field lines are much closer than in air.

89. Define uniform magnetic field. How is it represented geometrically?

Ans : Main 2012

A magnetic field is said to be uniform if a unit isolated north pole placed at different points in the field experiences the same force in the same direction.

Graphically, a uniform magnetic field is represented by equidistant and mutually parallel lines.



THREE MARKS QUESTIONS

90. What are artificial magnets? Give some of their advantages over natural magnets.

Ans : Main 2018, 2012

Artificial Magnets : Pieces of iron and other magnetic materials can be made to acquire the properties of natural magnets. Such magnets are called artificial magnets.

Advantages of Artificial Magnets Over Natural Magnets

1. They can be made magnetically much stronger than natural magnets.
2. They can be made of any convenient size and shape.
3. Their polarity can be reversed whenever desired.

91. State four basic properties of magnets.

Ans : SQP 2007

Basic properties of magnets are as follows :

1. **Attractive Property :** A magnet attracts small pieces of iron, nickel, cobalt, etc.
2. **Directive Property :** A freely suspended magnet aligns itself nearly in the geographic north-south direction.
3. **Like Poles Repel and Unlike Poles Attract :** This is a fundamental law of magnetic poles.
4. **Magnetic Poles Exist in Pairs :** Isolated magnetic poles do not exist. If we break a magnet into two pieces, we get two smaller dipole magnets.

92. Derive relation between relative magnetic permeability and magnetic susceptibility.

Ans : SQP 2012

In SI units, $B = \mu_0(H + I)$

Since, $I = \chi_m H$

Hence, $B = \mu_0(H + \chi_m H)$

$B = \mu_0 H(1 + \chi_m)$

Also, $B = \mu H$

Hence, $\mu H = \mu_0 H(1 + \chi_m)$

$\mu = \mu_0(1 + \chi_m)$

$\frac{\alpha}{\alpha_0} = 1 + \chi_m$

$\mu_r = 1 + \chi_m$

This is the required relation.

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93. Two identical iron bars A and B are given one of which definitely known to be magnetised. How would you ascertain, whether or not both are magnetised. If only one is magnetised?

Ans : SQP 2008

Since repulsion is the sure test of magnetisation, because if bar A attracts the other bar B, then both may be magnets (i.e. their unlike poles are facing each other) or one bar may be a simple piece of iron, but if there is a force of repulsion between them, then both bars must be magnetised.

To know which one is magnetised, place the bar A on the table and bring one of bar B near the two ends and at the middle of bar A. If there is force of attraction only at the ends of bar A, then bar A is magnetised and B not magnetised and if there is force of attraction both at the ends as well as at the middle, then bar B is magnetised and A is unmagnetised.

94. State Gauss's law of magnetism. What are its important consequences?

Ans : SQP 2025, 2005

Gauss's Law in Magnetism : This law states that the net magnetic flux through any closed surface is zero. Or, the surface integral of a magnetic field over a closed surface is zero. Mathematically,

$$\phi_B = \oint_S \vec{B} \cdot d\vec{S} = 0$$

Consequences of Gauss's Law :

1. Gauss's law indicates that there are no sources or sinks of magnetic field inside a closed surface. This implies that isolated magnetic poles (i.e., monopoles) do not exist.
2. The magnetic poles always exist as unlike pairs of equal strengths.
3. If a number of magnetic lines of force enter a closed surface, then an equal number of lines of force must leave that surface.

95. Define magnetic field and magnetic intensity (or magnetic field at a point). What is the S.I. unit of magnetic intensity?

Ans : Main 2016

Magnetic Field

The space around a magnet or a current carrying conductor in which the magnetic effect can be felt is called the magnetic field.

Magnetic Intensity

The strength of magnetic field or magnetic intensity at a point is the force experienced by a unit north pole placed at that point. The direction of the field is the direction in which this pole begins to move if free to do so.

Thus magnetic intensity is a vector quantity and has both magnitude and direction.

The S.I. unit of magnetic intensity is tesla or ampere meter.

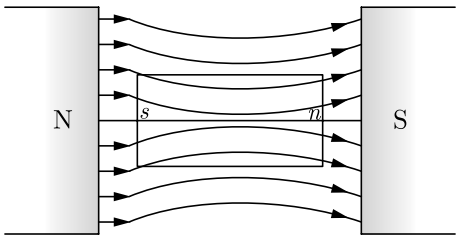
If a magnetic pole of strength m units placed at a point where the magnetic intensity is $\vec{B}$ then it experiences a force of $m\vec{B}$.

96. Give some important properties of ferromagnetic substances.

Ans : SQP 2014

Properties of ferromagnetic substances:

1. They are strongly attracted by magnets.
2. As shown in figure, the lines get highly concentrated in ferromagnetic material so that magnetic induction $B >> B_0$.



Highly Concentrated Lines of Force in a Ferromagnetic Rod

3. When placed in a non-uniform magnetic field, a ferromagnetic substance tends to move quickly from weaker to the stronger parts of the field.
4. When freely suspended, a rod of ferromagnetic material quickly aligns itself parallel to the magnetic field.
5. Their relative permeability is large, of the order of thousands.
6. Their susceptibility is large and positive.
7. Ferromagnetism decreases with the increase of temperature.

97. Distinguish between soft and hard ferromagnetic materials. Give examples of each type.

Ans : SQP 2017

Ferromagnetic materials can be divided into two categories:

1. **Soft Ferromagnetic Materials or Soft Ferromagnets :** These are the ferromagnetic materials in which the magnetisation disappears on the removal of the external magnetising field. They have low retentivity,

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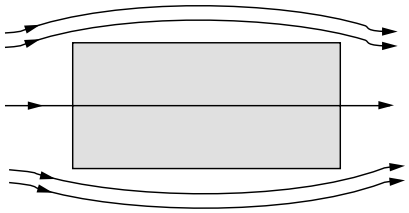


Diamagnetic substance (ii)

A paramagnetic material tends to move from weaker filed to stronger filed regions of the magnetic field.

So, the number of lines of magnetic field increases when passing through it.

Magnetic dipole moments are induced in the direction of magnetic field.

Paramagnetic materials has a small positive susceptibility.

A diamagnetic material tends to move from stronger field to weaker field region of the magnetic field. So, the number of lines of the magnetic field passing through it decreases.

Magnetic dipole moments are induced in the opposite direction of the applied magnetic field.

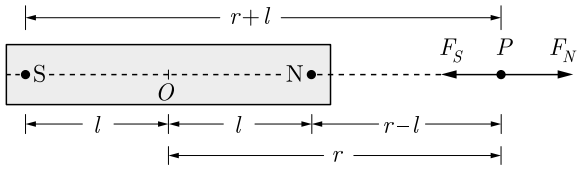
Diamagnetic materials has a negative susceptibility in the range ($-1 \leq \chi < 0$).

FOUR MARKS QUESTIONS

106. Derive an expression for the magnetic field intensity at a point on the axis of a bar magnet. What is the direction of the field?

Ans : Comp 2020

Magnetic field of a bar magnet at an axial point (end-on position). Let NS be a bar magnet of length $2l$ and of pole strength q_m. Suppose the magnetic field is to be determined at a point P. Which lies on the axis of the magnet at a distance r from its centre, as shown in figure.



Imagine a unit north pole placed at point P. Then from Coulomb's law of magnetic forces, the force exerted by the N-pole of strength q_m on unit north pole will be

$$F_N = \frac{\mu_0}{4\pi} \cdot \frac{q_m}{(r-l)^2}, \text{ along } \overrightarrow{NP}$$

Similarly, the force exerted by S-pole on unit north pole is

$$F_S = \frac{\mu_0}{4\pi} \cdot \frac{q_m}{(r-l)^2}, \text{ along } \overrightarrow{PS}$$

Therefore, the strength of the magnetic field $\vec{B}$ at point P is

B_{axial} = Force experienced by a unit north-pole at point P

$$= F_N - F_S$$

$$= \frac{\mu_0 q_m}{4\pi}\left[\frac{1}{(r-l)^2} - \frac{1}{(r+l)^2}\right]$$

$$= \frac{\mu_0 q_m}{4\pi} \cdot \frac{4rl}{(r^2-l^2)^2}$$

But $q_m \cdot 2l = m$, is the magnetic dipole moment, so

$$B_{\text{axial}} = \frac{\mu_0}{4\pi} \cdot \frac{2mr}{(r^2-l^2)^2}$$

For a short bar magnet, $l << r$, therefore, we have

$$B_{\text{axial}} = \frac{\mu_0}{4\pi} \cdot \frac{2m}{r^3}, \text{ along } \vec{N}P \qquad ...(1)$$

Clearly, the magnetic field at any axial point of magnetic dipole is in the same direction as that of its magnetic dipole moment.

107. Find time period of a bar magnet oscillating freely in a uniform magnetic field $\vec{B}$

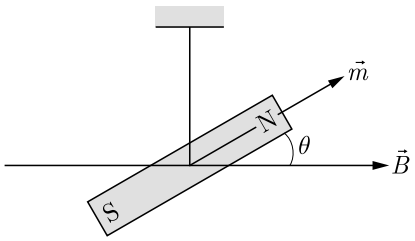
Ans : Comp 2021

Oscillations of a Freely Suspended Magnet in a Magnetic Field

In the position of equilibrium, the magnetic dipole lies along $\vec{B}$. When it is slightly rotated from this position and released, it begins to vibrate about the field direction under the restoring torque,

$$\tau = -mB\sin\theta$$

The negative sign indicates that the direction of toque τ is such so as to decrease θ.



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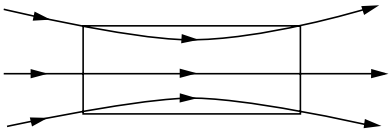
From eqs. (1) and (2), we have

$$\frac{M_S}{M_C} = \frac{NI\pi^2 R^2/4}{NI\pi R^2} = \frac{\pi}{4}$$

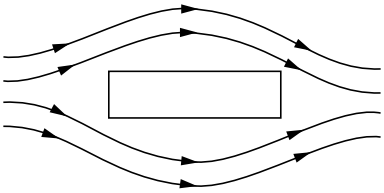
102. Three identical specimens of a magnetic materials nickel, antimony and aluminium are kept in a non-uniform magnetic filed. Draw the modification in the field lines in each case. Justify your answer.

Ans : SQP 2017, 2013

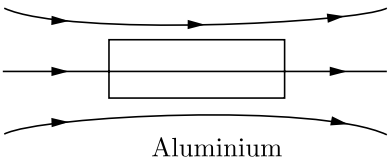
The modifications are shown in the figure.



Nickel



Antimony



Aluminium

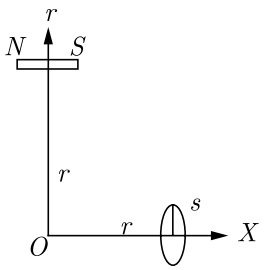
It happens because

(i) nickel is a ferromagnetic substance.

(ii) antimony is a diamagnetic substance.

(iii) aluminium is a paramagnetic substance.

103. A small magnet of magnetic moment M, is placed at a distance r from the origin O with its axis parallel to X-axis as shown. A small coil, if one turn is placed on the X-axis, at the same distance from the origin, with the axis of the coil coinciding with X-axis. For what value of current in the coil does a small magnetic needle, kept at origin, remains undefiled ? What is the direction of current in the coil ?



Ans : Comp 2010, 2008

This happens when magnetic field of bar magnet is equal and opposite to the magnetic field of coil

$$|\vec{B}_m| = |\vec{B}_c|$$

$$\frac{\mu_0 M}{4\pi r^3} = \frac{\mu_0 I a^2}{2r^3}$$

$$I = \frac{2M}{4\pi a^2}$$

Current is in anti-clockwise sense, an seen from the origin.

104. Derive an expression for the magnetic field at a point on the axis located at a distance x from the centre of a magnetic dipole of length $2l$ and magnetic moment M.

Ans : Main 2024

To find magnetic field at an axial point, we have to apply principle of superposition of magnetic field.

Consider the situation shown in the diagram. We have to find net magnetic field at point P, on axial point. Find magnetic field at P corresponding to each pole.

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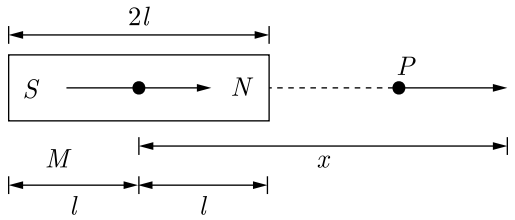


Net magnetic field at P,

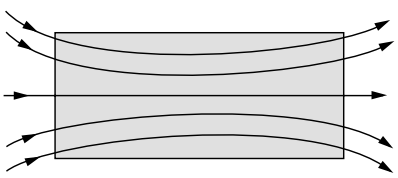
$$B = B_N - B_S$$

$$= \frac{\mu_0}{4\pi}\frac{2Mx}{(x^2 - l^2)^2}$$

$$\approx \frac{\mu_0}{4\pi}\frac{2M}{x^3} \qquad [\text{for } l << x]$$

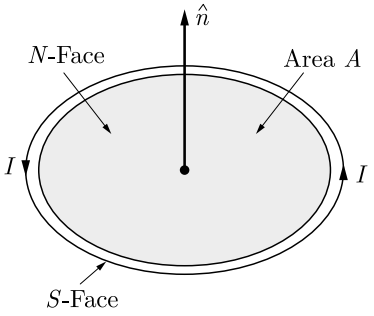
105. Show diagrammatically the behaviour of magnetic filed lines in the presence of (i) paramagnetic and (ii) diamagnetic substances, How does now explain this distinguishing feature?

Ans : Main 2014



Paramagnetic substance (i)

This result is valid for planer current loop of any shape. Thus the magnetic dipole moment of any current loop is equal to the product of the current and its loop area. Its direction is defined to be normal to the plane of the loop in the sense give by right hand thumb rule, as shown in figure.



Current Loop as a Magnetic Dipole

Right Hand Thumb Rule : If we curl the fingers of the right hand in the direction of current in the loop, then the extended thumb gives the direction of the magnetic moment associated with the loop.

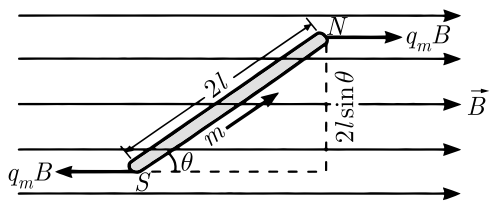
110. Derive an expression for the torque on a magnetic dipole placed in a magnetic field and hence define magnetic dipole moment.

Ans : **Main 2019**

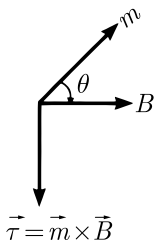
Torque on a magnetic dipole in a uniform magnetic field. Consider a bar magnet NS of length $2l$ placed in a uniform magnetic field $\vec{B}$. Let q_m be the pole strength of its each pole. Let the magnetic axis of the bar magnet make an angle θ with the field $\vec{B}$, as shown in Figure (a).

Force on N-pole $= q_m B$, along $\vec{B}$

Force on S-pole $= q_m B$, opposite to $\vec{B}$



(a)



(b)

The forces on the two poles are equal and opposite. They form a couple. Moment of couple or torque is given by,

$$\tau = \text{Force} \times \text{perpendicular distance}$$

$$= q_m B \times 2l \sin\theta = (q_m \times 2l)\, B \sin\theta$$

$$\tau = mB\sin\theta \qquad ...(1)$$

where, $m = q_m \times 2l$,

is the magnetic dipole moment of the bar magnet. In vector notation,

$$\vec{\tau} = \vec{m} \times \vec{B} \qquad ...(2)$$

The direction of the torque $\vec{\tau}$ is given by the right hand screw rule as indicated in Figure (b).

The effect of the torque $\vec{\tau}$ is to make the magnet align itself parallel to the field $\vec{B}$.

Definition of magnetic dipole moment. If in Eq. (1),

$$B = 1$$

Then, $\theta = 90^\circ$

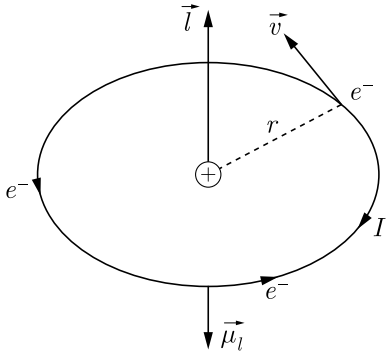
Hence, the magnetic dipole moment may be defined as the torque acting on a magnetic dipole placed perpendicular to a uniform magnetic field of unit strength.

111. Explain how does an atom behave as a magnetic dipole. Derive an expression for the magnetic dipole moment of the atom.

Ans : **Comp 2025**

Magnetic Dipole Moment of a Revolving Electron

In hydrogen-like atoms, an electron revolves around the nucleus. Its motion is equivalent to a current loop which possesses a magnetic dipole moment $= IA$. As shown in figure, consider an electron revolving anticlockwise around a nucleus in an orbit of radius r with speed v and time period T.



Orbital Magnetic Moment of a Revolving Electron

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For small angular displacement θ, $\sin\theta \approx \theta$.

Hence, $\tau = -mB\theta$

If I is the moment of inertia of the magnet, then the deflecting torque on the magnet is,

$$\tau = I\alpha = I\frac{d^2\theta}{dt^2}$$

In the equilibrium condition,

Deflecting torque = Restoring torque

Hence, $I\frac{d^2\theta}{dt^2} = -mB\theta$

or $\frac{d^2\theta}{dt^2} = -\frac{mB}{I}\theta$

$= -\omega^2\theta$

i.e. angular acceleration $\frac{d^2\theta}{dt^2} \propto$ angular displacement θ.

Hence, the oscillations of a freely suspended magnetic dipole in a uniform magnetic field are simple harmonic. The time period of oscillation is given by.

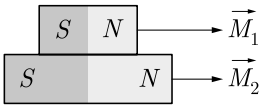
$$T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{I}{mB}}$$

108. How are the magnetic moment of two bar magnet compared without measuring their moment of inertia?

Ans : **SQP 2021**

Let us consider two magnets whose moment of inertia are I_1 and I_2 and magnetic moments are M_1 and M_2 respectively.

Sum Position



Net magnetic moment,

$$M_s = M_1 + M_2$$

Net moment of inertia,

$$I_s = I_1 + I_2$$

Time period of oscillation of this pair in earth's magnetic field B_H.

$$T_s = 2\pi\sqrt{\frac{I_s}{M_s B_H}}$$

$$= 2\pi\sqrt{\frac{I_1 + I_2}{(M_1 + M_2)\,B_H}} \quad ...(1)$$

Frequency, $v_s = \frac{1}{2\pi}\sqrt{\frac{(M_1 + M_2)\,B_H}{I_s}}$

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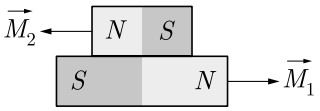
Difference Position

Net magnetic moment,



$$M_d = M_1 - M_2$$

Net moment of inertia,

$$I_d = I_1 + I_2$$

and $T_d = 2\pi\sqrt{\frac{I_d}{M_d B_H}}$

$$= 2\pi\sqrt{\frac{I_1 + I_2}{(M_1 - M_2)\,B_H}} \quad ...(2)$$

and $v_d = \frac{1}{2\pi}\sqrt{\frac{(M_1 + M_2)\,B_H}{(I_1 + I_2)}}$

From Eq. (1) and (2), we get

$$\frac{T_s}{T_d} = \sqrt{\frac{M_1 - M_2}{M_1 + M_2}}$$

$$\frac{M_1}{M_2} = \frac{T_d^2 + T_s^2}{T_d^2 - T_s^2}$$

$$= \frac{v_s^2 + v_d^2}{v_s^2 - v_d^2}$$

109. A current loop behaves as a magnetic dipole. Obtain an expression for the magnetic dipole moment of a circular loop. State the rule used to find the direction of the magnetic dipole moment.

Ans : **Main 2016, 2011**

The magnetic field produced at a large distance r form the centre of a circular loop (or radius a) along its axis is given by

$$B = \frac{\mu_0}{4\pi} \cdot \frac{2IA}{r^3} \quad ...(1)$$

On the other hand, the electric field of an electric dipole at an axial point lying far away from it is given by

$$E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2p}{r^3} \quad ...(2)$$

Where p is the electric dipole moment.

On comparing equations (1) and (2), we note that both B and E have same distance dependence $\left(\frac{1}{r^3}\right)$. Moreover, they have same direction at any far away point, not just on the axis.

This suggests that a circular current loop behaves as a magnetic dipole of magnetic moment,

$$m = IA$$

In vector notation,

$$\vec{m} = I\vec{A}$$

Clearly, the magnetic field at any equatorial point of a magnetic dipole is in the direction opposite to that of its magnetic dipole moment.

On comparing Eqs. (1) and (2), we note that the magnetic field at a point at a certain distance on the axial line of a short magnet is twice of that at the same distance on its equatorial line.

NUMERICAL QUESTIONS

113. A rectangular coil having 60 turns and area of $0.4\ \text{m}^2$is held at right angles to a uniform magnetic field of flux density $5 \times 10^{-2}\ \text{T}$. Calculate the magnetic flux passing through it.

Ans : **Main 2018**

The magnetic flux passing through a coil having N turns and area A is given by

$$\begin{aligned}\phi &= NBA \\ &= 60 \times 5 \times 10^{-2} \times 0.4 \\ &= 120 \times 10^{-2} \\ \phi &= 1.2\ \text{Wb}\end{aligned}$$

114. A bar magnet of magnetic moment $5.0\ \text{Am}^2$ has poles 20 cm apart. Calculate the pole strength.

Ans : **Comp 2016**

Given,

$$\begin{aligned}m &= 5.0\ \text{Am}^2 \\ 2l &= 20\ \text{cm} \\ &= 0.20\ \text{m}\end{aligned}$$

As, $m = q_m \times 2l$

Hence, Pole strength,

$$\begin{aligned}q_m &= \frac{m}{2l} \\ &= \frac{5.0}{0.20} = 25\ \text{Am}\end{aligned}$$

115. A magnetised needle of magnetic moment $4.8 \times 10^{-2}\ \text{JT}^{-1}$ is placed at 30° with the direction of uniform magnetic field of magnitude $3 \times 10^{-2}\ \text{T}$. What is the torque acting on the needle?

Ans : **SQP 2013**

Given, $m = 4.8 \times 10^{-2}\ \text{JT}^{-1}$

$\theta = 30^\circ$, $B = 3 \times 10^{-2}\ \text{T}$

Hence, Torque, $\tau = mB\sin\theta$

$$= 4.8 \times 10^{-2} \times 3 \times 10^{-2} \times \sin 30^\circ$$

$$= 7.2 \times 10^{-4}\ \text{J}$$

116. A planar loop of irregular shape encloses an area of $7.5 \times 10^{-4}\ \text{m}^2$ and carries a current of 12 A. The sense of flow of current appears to be clockwise to an observer. What is the magnitude and direction of the magnetic moment vector associated with the current loop?

Ans : **Main 2015, 2011**

Given, $A = 7.5 \times 10^{-4}\ \text{m}^2$

and $I = 12\ \text{A}$

Magnetic moment associated with the loop is,

$$\begin{aligned}m &= IA \\ &= 12 \times 7.5 \times 10^{-4} \\ &= 9.0 \times 10^{-3}\ \text{JT}^{-1}\end{aligned}$$

Applying right hand rule, the direction of magnetic moment is along the normal to the plane of the loop away from the observer.

117. At a certain place, the horizontal component of earth's magnetic field is $\sqrt{3}$ times its vertical component. What is the angle of dip at that place?

Ans : **Main 2025**

Horizontal components of earth's magnetic field,

$$B_H = \sqrt{3} \times B_V$$

where B_V = Vertical component of earth's magnetic field

The relation for the angle of dip δ at a place is,

$$\begin{aligned}\tan\delta &= \frac{B_V}{B_H} = \frac{B_V}{\sqrt{3} \times B_V} = \frac{1}{\sqrt{3}} \\ \delta &= 30^\circ\end{aligned}$$

118. An electron in an atom revolves around the nucleus in an orbit of radius $0.5\ \text{Å}$. Calculate the equivalent magnetic moment if the frequency of revolution of the electron is $10^{10}\ \text{MHz}$.

Ans : **Main 2011**

The electron revolving around the nucleus in a circular orbit is equivalent to a current loop.

Its magnetic moment is,

$$m = IA = e\nu \times \pi r^2$$

Given, $e = 1.6 \times 10^{-19}\ \text{C}$

$$\nu = 10^{10}\ \text{MHz} = 10^{16}\ \text{Hz}$$

$$r = 0.5\ \text{Å} = 0.5 \times 10^{-10}\ \text{m}$$

Therefore,

$$\begin{aligned}m &= 1.6 \times 10^{-19} \times 10^{16} \times 3.14 \times (0.5 \times 10^{-10})^2 \\ &= 1.257 \times 10^{-23}\ \text{Am}^2\end{aligned}$$

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$$\text{Current, } I = \frac{\text{Charge}}{\text{Time}} = \frac{e}{T}$$

$$= \frac{e}{2\pi r/v} = \frac{ev}{2\pi r}$$

Area of the current loop,

$$A = \pi r^2$$

The orbital magnetic moment of the electron is

$$\mu_l = IA = \frac{ev}{2\pi r} \cdot \pi r^2$$

or $$\mu_l = \frac{evr}{2} \quad ...(1)$$

According to right hand thumb rule, the direction of the magnetic dipole moment of the revolving electron will be perpendicular to the plane of its orbit and in the downward direction.

Also, the angular momentum of the electron due to its orbital motion is,

$$l = m_e vr \quad ...(2)$$

The direction of $\vec{l}$ is normal to the plane of the electron orbit and in the upward direction.

Dividing Eq. (1) by (2), we get

$$\frac{\mu_l}{l} = \frac{\frac{evr}{2}}{m_e vr} = \frac{e}{2m_e}$$

The above ratio is a constant called gyromagnetic ratio. Its value is $8.8 \times 10^{10}\,\text{Ckg}^{-1}$. So,

$$\mu_l = \frac{e}{2m_e} l$$

Vectorially, $$\vec{\mu}_l = -\frac{e}{2m_e}\vec{l}$$

The negative sign shows that the direction of $\vec{l}$ is opposite to that of $\vec{\mu}_l$. According to Bohr's quantisation condition, the angular momentum of an electron in any permissible orbit is,

$$l = \frac{nh}{2\pi}, (\text{where, } n = 1, 2, 3, ...)$$

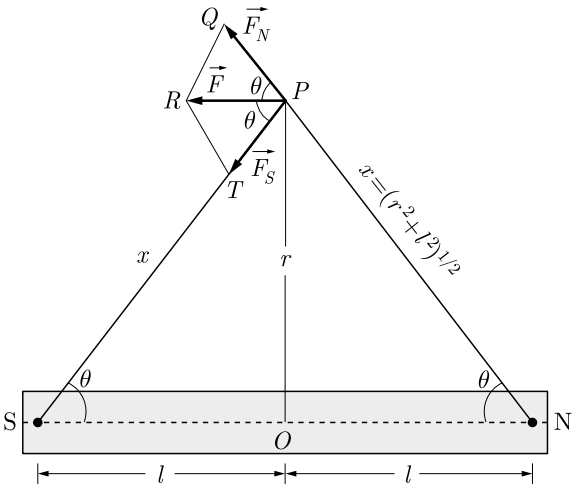
Hence, $$\mu_l = n\left(\frac{eh}{4\pi m_e}\right)$$

This equation gives orbital magnetic moment of an electron revolving in n^{th} orbit.

112. Derive an expression for the magnetic field intensity at a point on the equatorial line of a bar magnet. What is the direction of this field?

Ans : **SQP 2020, 2011**

Magnetic field of a bar magnet at an equatorial point (broadside-on position). Consider a bar magnet NS of length $2l$ and of pole strength q_m. Suppose the magnetic field is to be determined at a point P lying on the equatorial line of the magnet NS at a distance from its centre, as shown in figure.



Magnetic Field of a Bar Magnet at an Equatorial Point

Imagine a unit north-pole placed at point P. Then from Coulomb's law of magnetic forces, the force exerted by the N–pole of the magnet on unit north-pole is,

$$F_N = \frac{\mu_0}{4\pi} \cdot \frac{q_m}{x^2}, \text{ along } \overrightarrow{NP}$$

Similarly, the force exerted by the S-pole of the magnet on unit north-pole is

$$F_S = \frac{\mu_0}{4\pi} \cdot \frac{q_m}{x^2}, \text{ along } \overrightarrow{PS}$$

As the magnitudes of F_N and F_S are equal, so their vertical components get cancelled while the horizontal components add up along PR.

Hence the magnetic field at the equatorial point P is,

$$B_{\text{equa}} = \text{Net force on a unit } N\text{-pole placed at point } P$$

$$= F_N \cos\theta + F_S \cos\theta \quad [\text{Here } F_N = F_S]$$

$$= 2F_N \cos\theta$$

$$= 2 \cdot \frac{\mu_0}{4\pi} \cdot \frac{q_m}{x^2} \cdot \frac{1}{x}$$

or $$B_{\text{equa}} = \frac{\mu_0}{4\pi} \cdot \frac{m}{(r^2 + l^2)^{3/2}}$$

$[\text{since } x = (r^2 + l^2)^{1/2}]$

where, $m = q_m \cdot 2l$ is the magnetic dipole moment.

Again for a short magnet, $l << r$, so we have

$$B_{\text{equa}} = \frac{\mu_0}{4\pi} \cdot \frac{m}{r^3}, \text{ along } \overrightarrow{PR} \quad ...(2)$$

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low coercivity, and low hysteresis loss. But they have high relative magnetic permeability. They are used as cores of solenoids and transformers.

Examples: Soft iron, mu metal, stalloy, etc.

2. **Hard Ferromagnetic Materials or Hard Ferromagnets :** These are the ferromagnetic materials which retain magnetisation even after the removal of the external magnetising field. They have high retentivity, high coercivity and large hysteresis loss. They are used for making permanent magnets.

Examples: Steel, alnico, lodestone, ticonal, etc.

98. Explain the following

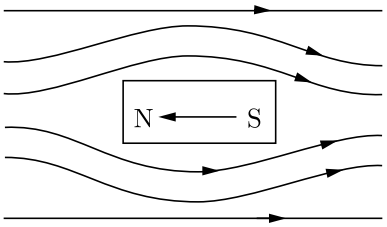
(1) Why do magnetic field lines form continuous closed loops?

(2) Why are the filled lines repelled (expelled) when a diamagnetic material is placed in a external uniform magnetic field?

Ans : **Main 2012**

(1) Magnetic lines of force form continuous closed loops because a magnet is always a dipole and as a result, the net magnetic flux of a magnet is always zero.

(2) When a diamagnetic substance is placed in an external magnetic field, a feeble magnetism is induced on opposite direction. So, magnetic lines of force are repelled.



99. Distinguish between diamagnetic and ferromagnetic materials in terms of

(1) Susceptibility and

(2) their behaviour in a non-uniform magnetic filed.

Ans : **Main 2011**

(1) **Susceptibility for diamagnetic material :** It independent of magnetic filed and temperature (exec) for bismuth at low temperature.

Susceptibility for ferromagnetic material : The Susceptibility of ferromagnetic materials decrease steadily with increase in temperature. At the temperature, the ferromagnetic materials become paramagnetic.

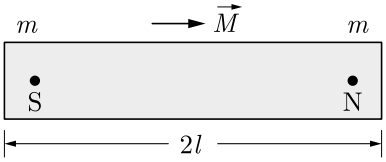
(2) Behaviour in non-uniform magnetic field Diamagnetic are feebly repelled, whereas ferromagnet are strongly attracted by non-uniform filed i.e., diamagnetic move it, the direction of decreasing filed, whereas ferromagnet feels force in direction of increasing filed intensity.

100. Define magnetic dipole and dipole moment. What are its units?

Ans : **SQP 2024, 2010**

Magnetic Dipole : An arrangement of two magnetic poles of equal and opposite strength separated by a finite distance is said to constitute a magnetic dipole. Common examples of magnetic dipoles are compass needle, a bar magnet, a current loop, an electron revolving in a circular or elliptical path etc.

Magnetic Dipole Moment : Consider a magnetic consisting of two poles N and S each having pole strength m as shown in the figure. The distance between two poles is called magnetic length.



Magnetic dipole moment is the product of strength of either pole and the magnetic length.

i.e., $\vec{M} = m(2\vec{l})$

The direction of magnetic dipole moment is from south to north pole.

Unit : In SI the unit of dipole moment is ampere metre^2 (Am^2).

101. A coil of N turns and radius R carries a current f it is unwound and rewound to make a square coil of side a having same number of turns (N). Keeping the current I same, find the ratio of the magnetic moments of the square coil and the circular coil.

Ans : **SQP 2015**

The magnetic moment of a current loop is given by the relation $M = NIA$

For the circular loop

$$M_c = NI\pi R^2 \qquad ...(1)$$

Now, When the coil is unwound and rewound to make a square coil, then

$$M_S = NI\,a^2 = NI(\pi R/2)^2$$

$$= NI\pi^2 R^2/4 \qquad ...(2)$$

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119. A compass needle whose magnetic moment is $60\ \text{Am}^2$ pointing geographical north at a certain place where the horizontal component of earth's magnetic field is $40\ \mu\text{Wb/m}^2$ experiences a torque of $1.2 \times 10^{-3}\ \text{Nm}$. What is the declination of the place?

Ans : **Main 2009**

In stable equilibrium, a compass needle points along magnetic north and experiences no torque. When it is turned through declination α, it points along geographic north and experiences torque,

$$\tau = mB\sin\alpha$$

Hence, $$\sin\alpha = \frac{\tau}{mB}$$

$$= \frac{1.2 \times 10^{-3}}{60 \times 40 \times 10^{-6}} = \frac{1}{2}$$

$$\alpha = 30^\circ$$

120. A magnet of magnetic moment M is freely suspended in a uniform magnetic field of strength B. Calculate the work done in rotating the magnet through 60° to 90° ?

Ans : **Comp 2018**

$$\text{Magnetic moment} = M$$

$$\text{Strength of magnetic field} = B$$

$$\text{Initial angle of rotation} = 60^\circ$$

$$\text{Final angle of rotation} = 90^\circ$$

The work done in rotating the magnet in uniform magnetic field,

$$W = MB(\cos\theta_1 - \cos\theta_2)$$

$$= MB(\cos 60^\circ - \cos 90^\circ)$$

$$= MB\left(\frac{1}{2} - 0\right) = \frac{MB}{2}$$

121. Obtain the earth's magnetisation. Assume that the earth's field can be approximated by a giant bar magnet of magnetic moment $8.0 \times 10^{22}\ \text{Am}^2$. The earth's radius is 6400 km.

Ans : **SQP 2005**

Magnetic moment,

$$m = 8.0 \times 10^{22}\ \text{Am}^2$$

Radius of the earth,

$$R = 6400\ \text{km} = 6.4 \times 10^6\ \text{m}$$

Magnetisation, $$M = \frac{m}{V}$$

$$= \frac{m}{\frac{4}{3}\pi r^3}$$

$$= \frac{8.0 \times 10^{22} \times 3}{4 \times 3.14 \times (6.4 \times 10^6)^3}$$

$$= 72.9\ \text{Am}^{-1}$$

122. The electron in the hydrogen atom is moving with a speed of $2.3 \times 10^6\ \text{ms}^{-1}$ is an orbit of radius 0.53 Å. Calculate the magnetic moment of the revolving electron.

Ans : **SQP 2016**

Given, $v = 2.3 \times 10^6\ \text{ms}^{-1}$

$r = 0.53$ Å

$= 0.53 \times 10^{-10}\ \text{m}$

$e = 1.6 \times 10^{-19}\ \text{C}$

Orbital magnetic moment of the electron,

$$\mu_l = \frac{evr}{2}$$

$$= \frac{1.6 \times 10^{-19} \times 2.3 \times 10^6 \times 0.53 \times 10^{-10}}{2}$$

$$= 9.75 \times 10^{-24}\ \text{Am}^2$$

123. What is the magnitude of the equatorial and axial fields due to a bar magnet of length 5 cm at a distance of 50 cm form the midpoint? The magnetic moment of the bar magnet is $0.40\ \text{Am}^2$.

Ans : **Main 2018**

Given, $m = 0.40\ \text{Am}^2$

$r = 50\ \text{cm} = 0.50\ \text{m}$

$2l = 5.0\ \text{cm}$

Clearly, the magnet is a short magnet ($l << r$).

1. $$B_{\text{equa}} = \frac{\mu_0}{4\pi} \cdot \frac{m}{r^3}$$

$$= \frac{10^{-7} \times 0.4}{(0.5)^3}$$

$$= 3.2 \times 10^{-7}\ \text{T}$$

2. $$B_{\text{axial}} = \frac{\mu_0}{4\pi} \cdot \frac{2m}{r^3}$$

$$= 2 \times 3.2 \times 10^{-7}$$

$$= 6.4 \times 10^{-7}\ \text{T}$$

124. A bar magnet of magnetic moment 6.4 A-m^2 is placed in a uniform magnetic field of 0.4 T. What is the torque acting on the magnet, when its axis makes an angle of 60° with the magnetic field?

Ans : **Comp 2007**

Magnetic moment, $M = 6.4$ A-m^2

Magnetic field, $B = 0.4$ T

and angle between bar magnet and magnetic field,

$$\theta = 60^\circ$$

Torque acting on the bar magnet in uniform filed,

$$\tau = MB\sin\theta$$

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CHAPTER 6

Electromagnetic Induction

SUMMARY

1. MAGNETIC FLUX

The total number of magnetic field lines crossing through any surface normally when it placed in a magnetic field is known as the magnetic flux through that surface.

2. FARADAY'S LAW OF EMI

Faraday gave two laws of EMI which sre as follows:

1. **First Law :** An emf is induced in a circuit when the magnetic flux linked with circuit charges.
2. **Second Law :** The magnitude of induced emf in a circuit is equal to the rate of change of magnetic flux through the circuit.

3. INDUCED EMF AND CURRENT

Induced emf and current is given by the following formula :

Induced emf, $e = -N\frac{d\phi_B}{dt}$

Induced current, $I = \frac{e}{R} = \frac{-N}{R}\frac{d\phi_B}{dt}$

Here, R = resistance of the circuit

and N = number of turns

4. LENZ'S LAW

According to this law, the polarity of induced emf is such that it tends to produce a current which oppose the change in magnetic flux produced it.

5. FLEMING'S RIGHT HAND RULE

If we stretch the thumb, the forefinger, the central finger of our right hand in such a way that all three are mutually perpendicular to each other, then if the thumb represents the direction of force, forefinger represent the direction of magnetic field, then the central finger will represent the direction of induced current.

6. INDUCED CURRENT IN A CIRCUIT

If induced current is produced in a coil rotated in a uniform magnetic field, then

$$I = I_0 \sin \omega t$$

7. MOTIONAL EMF AND FARADAY'S LAW

If e is the induced emf, then according to Faraday's law,

$$e = (-d\phi/dt) = -Blv$$

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8. ENERGY CONSIDERATION

Power required to move conductor in a uniform magnetic field perpendicular is,

$$P = \frac{B^2 l^2 v^2}{R}$$

Here, R = resistance of the circuit through which current is flowing.

B = a uniform magnetic field

l = length of the conductor

v = speed

9. INDUCTANCE

It is the ratio of the flux to the current. It depends on the geometry of the coil and intrinsic material properties.

9.1 Self-inductance

It in the property of a coil by virtue of which it opposes any changes in the strength of current flowing through it by inducing an emf in itself. When current in a coil changes, it induces a back emf in the same coil. The self-induced emf is given by, $e = -L\frac{dI}{dt}$, where L is the self-inductance of the coil. If coil of N turns and area A is rotated with

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and final angle through which magnet is turned,

$$\theta_2 = 60^\circ$$

work done in turning the bar magnet,

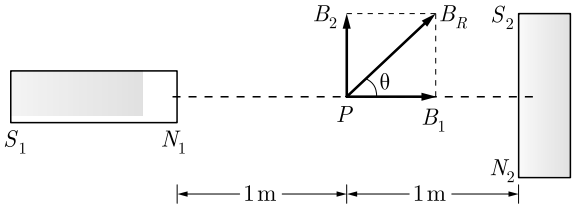
$$W = MB(1 - \cos\theta)$$

Therefore,
$$\frac{W_1}{W_2} = \frac{1 - \cos\theta_1}{1 - \cos\theta_2}$$
$$= \frac{1 - \cos 90^\circ}{1 - \cos 60^\circ}$$
$$= \frac{1 - 0}{1 - 0.5}$$
$$= \frac{1}{0.5} = 2$$
$$W_1 = 2\,W_2$$
$$\frac{W_1}{W_2} = 2 \qquad (\text{where, } n = \frac{W_1}{W_2})$$

129. Two identical magnetic dipoles of magnetic moments 1.0 Am^2 each are placed at a separation of 2 m with their axes perpendicular to each other. What is the resultant magnetic field at a point mid-way between the dipoles?

Ans : **Comp 2024**

The situation is shown in figure.



The magnetic fields of the two magnets at the midpoint P are,

$$B_1 = \frac{\mu_0}{4\pi} \cdot \frac{2m}{r^3}$$
$$= \frac{10^{-7} \times 2 \times 1}{1^3}$$
$$= 2 \times 10^{-7}\ \text{T}$$

(in horizontal direction)

$$B_2 = \frac{\mu_0}{4\pi}\frac{m}{r^3} = 10^{-7}\ \text{T}$$

(in vertical direction)

Hence, $B_R = \sqrt{B_1^2 + B_2^2} = \sqrt{5} \times 10^{-7}\ \text{T}$

If the resultant field B_R makes angle θ with B_1, then

$$\tan\theta = \frac{B_2}{B_1} = \frac{10^{-7}}{2 \times 10^{-7}} = 0.5$$

Hence, $\theta = 26.57^\circ$

130. The effective length of a magnet is 31.4 cm, and its pole strength is 0.5 A-m. If it is bent in the form of a semicircle. What is the new magnetic moment?

Ans : **Main 2010**

Initial effective length of magnet or initial distance between the poles,

$$d_1 = 31.4\ \text{cm} = 0.314\ \text{m}$$

and pole strength of the magnet,

$$m = 0.5\ \text{A-m}$$

Initial magnetic moment,

$$M_1 = m \times d_1$$
$$= 0.5 \times 0.314$$
$$= 0.157\ \text{A-m}^2$$

We also know that when a magnet is bent to from a semicircle, then distance between the poles

= Diameter of semicircle

$$d_2 = \frac{2d_1}{\pi} = \frac{2 \times 0.314}{3.14} = 0.2\ \text{m}$$

We also know that magnetic moment of magnet

M = Pole strength × Distance between the poles

$$= m \times d$$

i.e., $= M \propto d$

Therefore, $\frac{M_1}{M_2} = \frac{d_1}{d_2} = \frac{0.314}{0.2} = 1.57$

where M_2 = New Magnetic moment of magnet

$$M_2 = \frac{M_1}{1.57}$$
$$= \frac{0.157}{1.57} = 0.1\ \text{A-m}^2$$

131. A current of 7.0 A is flowing in a plane circular coil of radius 1.0 cm having 100 turns. The coil is placed in a uniform magnetic field of 0.2 Wbm^{-2}. If the coil is free to rotate, what orientations would correspond to its (1) stable equilibrium and (2) unstable equilibrium? Calculate the potential energy of the coil in these cases.

Ans : **SQP 2006**

Given, $N = 100$

$A = 7.0\ \text{A}$

$r = 1.0\ \text{cm} = 1.0 \times 10^{-2}\ \text{m}$

$B = 0.2\ \text{Wbm}^{-2}$

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Ans : **Main 2009**

An AC dynamo or generator produces electrical energy from mechanical work, just the opposite of what a motor does. In it a shaft is rotated by some mechanical means such as an engine or a turbine starts working and an emf is induced in the coil.

Thus (b) is correct option.

7. The Lenz's law gives

(a) direction of induced E.M.F.

(b) magnitude of induced E.M.F.

(c) direction of induced current.

(d) magnitude of induced current.

Ans : **SQP 2004**

The Lenz's law gives the direction of the induced current in electromagnetic induction.

According to this law, the direction of induced current is such that it opposes the cause which produces it.

Thus (c) is correct option.

8. Which of the following does not obey the phenomenon of mutual induction?

(a) dynamo (b) transformer

(c) induction coil (d) electric heater

Ans : **SQP 2008**

The phenomenon according to which an opposing E.M.F. is produced in a coil as a result of change in current or magnetic flux linked with a neighbouring coil, is called mutual induction.

Since electric heater is based on heating effect of current, therefore it does not obey the phenomenon of mutual induction.

And dynamo, transformer and induction coils are based on the phenomenon of the mutual induction.

Thus (d) is correct option.

9. The mutual inductance, when the magnetic flux changes by 5×10^{-2} Wb and current change by 0.01 A, is

(a) 0.2 H (b) 2.5 H

(c) 5 H (d) 10 H

Ans : **Main 2011, 2008**

Change in magnetic flux,

$$d\phi = 5 \times 10^{-2}\,\text{Wb}$$

Change in current, $dI = 0.01\,\text{A}$

Mutual inductance, $M = \dfrac{d\phi}{dI}$

$$= \frac{5 \times 10^{-2}}{0.01} = 5\,\text{H}$$

Thus (c) is correct option.

10. The mutual inductance of two coils can be increased by

(a) increasing the length of coils

(b) increasing the no. of turns in the coils

(c) winding the coils on wooden cores

(d) decreasing the no. of turns in the coils

Ans : **SQP 2003**

Mutual inductance of coils,

$$M = \frac{\mu_0 N_1 N_2 A}{l}$$

Therefore, it can be increased by increasing no. of turns in the coils and decreasing the length of coils.

Thus (b) is correct option.

11. Two coils are placed close to each other. The mutual inductance of the pair of coils depends upon

(a) currents in the coils

(b) materials of the wires of the coils

(c) relative position and orientation of the coils

(d) rates at which the currents are changing in the coils

Ans : **Main 2011**

Mutual inductance of the pair of coils depends upon the geometry of the coils, distance between the coils, relative position and orientation of the coils, no. of turns in the coils, permeability of the medium in which the coils wounded and degree of coupling i.e., the extent to which the magnetic flux primary current links the secondary.

Thus (c) is correct option.

12. A small piece of metal wire is dragged across the gap between the poles of a magnet in 0.4 s. If change in magnetic flux in the wire is 8×10^{-4} Wb, then E.M.F. induced in the wire is

(a) 8×10^{-3} V (b) 6×10^{-3} V

(c) 4×10^{-3} V (d) 2×10^{-3} V

Ans : **SQP 2011**

Time-taken $dt = 0.4\,\text{s}$ and change in magnetic flux $d\phi = 8 \times 10^{-4}$ Wb.

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134. A ferromagnetic substance consists of local regions called 'domains', each of which is spontaneously magnetised. In an unmagnetised substance the directions of magnetisation in different domains are different so that, on an average, the resultant magnetisation is zero.

When we magnetise the substance by placing it in an external magnetising field, then those domains which are favourably oriented with respect to the external field grow in size and also each domain rotates so that its direction of magnetisation becomes aligned with the field direction.

During this process energy is taken by the substance. When the external field is removed, the domain boundaries do not move completely back to their original positions, that is, the substance retains some magnetisation (hysteresis effect). Therefore, the energy supplied to the substance during magnetisation is not fully recovered. The balance of energy left in the substance is lost as heat. This is called 'hysteresis loss'.

(i) What do you mean by hysteresis loss?

(ii) What do you mean by hysteresis effect?

(iii) Define the term 'Domains'.

(iv) In which material have smaller hysteresis loss iron or steel?

(v) How can we reduce the hysteresis loss?

Ans :

(i) During the cycle of magnetisation and demagnetisation of magnetic substances, energy is spent and this is spent energy appears, in the form of heat. This heat loss is known as hysteresis loss.

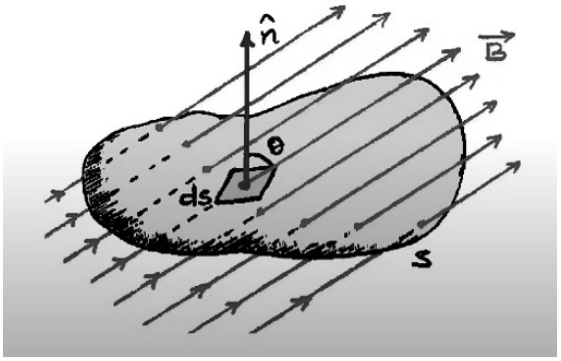
(ii) When the magnetisation of ferromagnetic materials lags behind the magnetic field. This effect can be described as the hysteresis effect.

(iii) A ferromagnetic substance consists of local regions called domains.

(iv) In soft iron has smaller hysteresis loss than of steel.

(v) Hysteresis losses can be reduced by using material that has less area of the hysteresis loop

135. A physics teacher explain Gauss's theorem in electrostatics and Gauss's theorem in magnetism to his students in a class. He tells them that total normal electric flux over a closed surface in vacuum is $\phi_e = \frac{Q}{\varepsilon_0}$, where Q is algebraic sum of charges inside the surface. Further, total normal magnetic flux over a closed surface in vacuum is always zero. The teacher emphasises that this is because in magnetism, poles always exist in unlike pairs of equal strength i,e., isolated magnetic poles called monopoles not exist.



Read the above passage and answer the following questions

(i) What are the implications of Gauss's theorem in magnetism in day-to-day life?

(ii) Two magnetic dipoles of moments 5 $A-m^2$ and 3 $A-m^2$ oriented along opposite directions are enclosed in a surface. What is total normal magnetic flux over the surface?

(iii) Two points charges $+4q$ and-q are enclosed in a surface in vacuum and third change $5q$ lies outside the surface. What is total normal electric flux over the surface?

Ans :

(i) In day-to-day life, we can visualize North pole of a magnetic dipole as source and South pole of the dipole as sink. When source and sink (of magnetic flux) having the same strength are enclosed by a surface, the total normal magnetic flux from the surface (i.e., net out come) will be zero. Hence, to archive success in any sphere of life, we must identify the sinks and plug them properly. Arrange to have as many sources as possible and success will yours.

(ii) As stated in theorem, total normal magnetic flux over the surface would always be zero, it being zero for every individual magnetic dipole.

(iii) $$\phi_e = \frac{\sum q_{\text{inside}}}{\varepsilon_0} = \frac{4q - q}{\varepsilon_0} = \frac{3q}{\varepsilon_0}$$

The charge $5q$ outside the surface does not affect the electric flux.

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$$= 6.4 \times 0.4 \times \sin 60^\circ$$
$$= 6.4 \times 0.4 \times 0.866$$
$$= 2.2 \text{ N-m}$$

125. A current of 6 A is flowing through a 10 turn circular coil of radius 7 cm. The coil lies in the x-y plane. What is the magnitude and direction of the magnetic dipole moment associated with it?

If this coil were to be placed in a uniform external magnetic field directed along the x-axis, in which plane would the coil lie, when in equilibrium? (Take $\pi = 22/7$)

Ans : SQP 2017, 2010

Magnetic dipole moment,

$$m = NIA = NI \times \pi r^2$$
$$= 10 \times 5 \times \frac{22}{7} \times \left(\frac{7}{100}\right)^2$$
$$= 0.77 \text{ Am}^2$$

The direction of magnetic dipole moment is perpendicular to the plane of the coil. Hence it is along z-axis.

Torque on the current loop of magnetic moment m is,

$$\tau = mB \sin\alpha$$

where, α is angle between $\vec{m}$ and $\vec{B}$. For stable equilibrium torque is zero, so $\alpha = 0^\circ$. For this $\vec{B}$ should be perpendicular to the plane of the coil. Hence the coil will lie in y-z plane in the condition of stable equilibrium.

126. A short bar magnet placed with its axis at 30° to a uniform magnetic field of 0.2 T experiences a torque of 0.06 Nm.

1. Calculate the magnetic moment of the magnet.
2. Find out what orientation of the magnet corresponds to its stable equilibrium in the magnetic field.

Ans : Main 2010

1. Given,

$$B = 0.2 \text{ T}$$
$$\theta = 30^\circ$$
$$\tau = 0.06 \text{ Nm}$$

Magnetic moment,

$$m = \frac{\tau}{B \sin\theta} = \frac{0.06}{0.2 \sin 30^\circ}$$
$$= \frac{0.06}{0.2 \times 0.5}$$
$$= 0.6 \text{ Am}^2$$

2. The potential energy of a magnetic dipole in a uniform magnetic field is

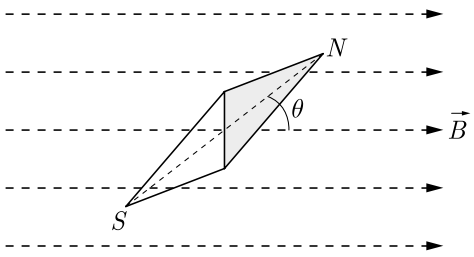
$$U = -mB\cos\theta$$

In stable equilibrium, the potential energy is minimum. So

$$\cos\theta = 1$$
$$\theta = 0^\circ$$

Hence the bar magnet will be in stable equilibrium when its magnetic moment $\vec{m}$ is parallel to the magnetic field $\vec{B}$.

127. In figure, a magnetic needle is free to oscillate in a uniform magnetic field. The magnetic needle has magnetic moment 6.7 Am^2 and moment of inertia $I = 7.5 \times 10^{-6}$ kg m^2. It performs 10 complete oscillations in 6.70s. What is the magnitude field?



Ans : Main 2016

Given $T = \frac{6.70 \text{ s}}{10} = 0.67 \text{ s}$

$m = 6.7 \text{ Am}^2$

$I = 7.5 \times 10^{-6} \text{ kg m}^2$

As, $T = 2\pi\sqrt{\frac{I}{mB}}$

$$T^2 = 4\pi^2 \frac{I}{mB}$$

The magnitude of the magnetic field is,

$$B = \frac{4\pi^2 I}{mT^2}$$
$$= \frac{4 \times 9.87 \times 7.5 \times 10^{-6}}{6.7 \times (0.67)^2}$$
$$= 9.8 \times 10^{-5} \text{ T}$$

128. Work done in turning a bar magnet of magnetic moment M through 90° from the meridian, is n times the corresponding work done to turn it through an angle of 60°. What is the value of n ?

Ans : SQP 2016, 2011

Magnetic moment $= M$

Initial angle through which magnet is turned,

$$\theta_1 = 90^\circ$$

v revolution per second in a uniform magnetic field B, then the induced emf is,

$$e = e_0 \sin\omega t$$
$$= NAB\,\omega \sin\omega t$$
$$= NBA\,(2\pi v)\,\sin(2\pi v)\,t.$$

Self-inductance of a Long Solenoid

Self-inductance of a long solenoid is given by

$$L = \frac{\mu_0 N^2 A}{I}$$

Where N = Number of twos in solenoids

A = Area of cross section of a coil.

I = Current flowing in solenoid.

9.2 Mutual Inductance

The phenomenon according to which an opposing emf is produced as a result of change in current or magnetic flux linked with a neighbouring coil.

Mutual Inductance of Two Long Coaxial Solenoids

Mutual inductance of two long coaxial solenoids is given by,

$$M = \frac{\mu_0 N_1 N_2 A}{I}$$

OBJECTIVE QUESTIONS

1. Two coils P and S are wound on a common core, their coefficient of mutual inductance does not depend on

(a) number of turns in the coil P

(b) number of turns in the coil S

(c) material of the core

(d) voltage applied to the coil P or Q

Ans : Main 2022 Sem-I

The coefficient of mutual inductance depends on the number of turns in both coils, the arrangement of coils, and the material of the core. It does not depend on the applied voltage. Therefore, changing the voltage does not affect mutual inductance. Thus (d) is correct option.

2. Faraday's laws are the consequence of the conservation of

(a) charge (b) energy

(c) magnetic field (d) both (b) and (c)

Ans : SQP 2012

Faraday's laws involve conversion of mechanical energy into electrical energy. Thus they are in accordance with the law of conservation of energy.

Thus (b) is correct option.

3. S.I. unit of self-inductance is

(a) coulomb (b) volt

(c) ohm (d) henry

Ans : SQP 2016, 2015

Self inductance, $L = \frac{e}{dI/dt}$

S.I Unit of $L = \frac{1\,V}{1\,AS^{-1}}$

$= 1VSA^{-1} = 1$ henry

Thus (d) is correct option.

4. The loss of power in a transformer can be reduced by

(a) increasing the number of turns in primary coil.

(b) increasing AC voltage applied to primary coil.

(c) using a solid core made of steel.

(d) using a laminated core of soft iron.

Ans : Main 2010, 2007

Power loss in a transformer is reduced by using a laminated soft iron core. Lamination decreases eddy current losses, while soft iron reduces hysteresis loss due to its easy magnetisation and demagnetisation. Hence, transformers are made with laminated soft iron cores for better efficiency.

Thus (d) is correct option.

5. Lenz's law is associated with principle of conservation of

(a) charge (b) mass

(c) energy (d) momentum

Ans : Main 2025, 2015

In each case whenever there is relative motion between a coil and the magnet a force begins to act which opposes the relative motion therefore to maintain the relative motion, a mechanical work must be done. This work appears in the form of electric energy of coil. Thus lenz's law is based on principle of conservation of energy.

Thus (c) is correct option.

6. To convert mechanical energy into electrical energy one can use

(a) D.C. dynamo (b) A.C. dynamo

(c) Motor (d) Transformer

NODIA

Area of solenoid,

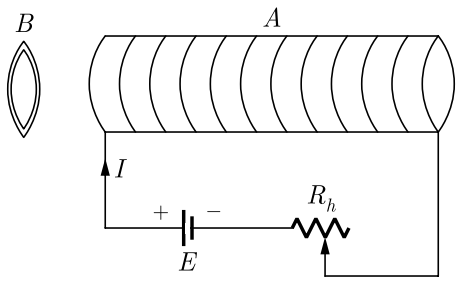
$$A = \pi r^2$$
$$= \pi \times (0.02)^2$$
$$= 4\pi \times 10^{-4}\,\text{m}^2$$

Therefore, mutual inductance of two solenoids,

$$M = \frac{\mu_0 N_1 N_2 A}{l}$$
$$= \frac{(4\pi \times 10^{-7}) \times 2000 \times 1000 \times (4\pi \times 10^{-4})}{2}$$
$$= 1.6 \times 10^{-3}\,\text{H}$$
$$= 1.6\,\text{mH}$$

Thus (b) is correct option.

18. An aluminium ring B faces an electromagnet A. Which of the following statement is correct?



(a) If I increases, A will repel B.

(b) If I decreases, A will repel B.

(c) If I increases, A will attract B.

(d) Whether I increases or decreases B will not experience any force.

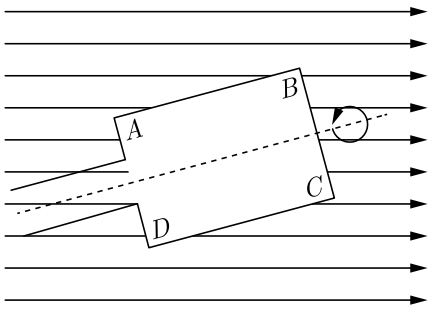
Ans : **Main 2003, 2000**

When circuit is closed, increasing current in the coils of electromagnet A produces time varying magnetic flux which magnetised it.

We also know from Lenz's law that when time varying magnetic flux links with a nearby ring, then direction of induced current (or E.M.F.) in the ring will be such that it opposes the cause which produces it.

Thus (a) is correct option.

19. A rectangular coil $ABCD$ is rotated anticlockwise with a uniform angular velocity about the axis shown in the figure. Initially, the axis of rotation of the coil as well as the magnetic field B were horizontal. The induced E.M.F. in the coil would be maximum when plane of the coil



(a) is horizontal

(b) is at right angle to the magnetic field

(c) makes an angle of 30° with the horizontal

(d) makes an angle of 45° with the direction of magnetic field

Ans : **Main 2024**

E.M.F. induced in the coil when rotated in magnetic field,

$$E = E_0 \sin\theta$$
$$= E_0 \sin\omega t$$

where, $\theta =$ angle between plane of coil and vertical

Therefore, for maximum induced E.M.F., the value of $\sin\theta$ should be maximum.

Thus, $\sin\theta = 1$

$\theta = 90^\circ$

Therefore induced E.M.F. (E) in coil $ABCD$ would be maximum when plane of coil is horizontal (i.e., makes an right angle to the vertical).

Thus (a) is correct option.

20. The magnetic flux through a circuit of resistance R changes by an amount $\Delta\phi$ in a time Δt. The total electric charge Q that passes any point in the circuit during the time Δt is represented by

(a) $Q = \frac{\Delta\phi}{\Delta t}$ (b) $Q = \frac{\Delta\phi}{R}$

(c) $Q = R \cdot \frac{\Delta\phi}{\Delta t}$ (d) $Q = \frac{1}{R} \cdot \frac{\Delta\phi}{\Delta t}$

Ans : **SQP 2009**

Resistance of circuit $= R$;

Change in magnetic flux $= \Delta\phi$;

Time-taken $= \Delta t$ and

Total charge that passes any point in the circuit $= Q$.

E.M.F. induced in the circuit,

$$E = \frac{\Delta\phi}{\Delta t}$$

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E.M.F. induced in the wire,

$$E = \frac{d\phi}{dt}$$
$$= \frac{8 \times 10^{-4}}{0.4}$$
$$= 2 \times 10^{-3}\,\text{V}$$

Thus (d) is correct option.

13. The working of dynamo is based on the principle of

(a) heating effect of current

(b) electromagnetic induction

(c) magnetic induction

(d) electric induction

Ans : **Main 2016, 2015**

The working of dynamo or AC generator is based on the principle of electromagnetic induction. When a closed coil is rotated in uniform magnetic field with it axis perpendicular to the magnetic field, the magnetic flux linked with coil changed and an induced emf is set up in the coil hence a current is set up in it.

Thus (b) is correct option.

14. An infinitely long conducting cylinder is kept parallel to a uniform magnetic field B directed along positive z-axis. The direction of induced current on the surface of cylinder as seen from the z-axis will be

(a) zero

(b) clockwise of the positive z-axis

(c) along the magnetic field

(d) anticlockwise of the positive z-axis

Ans : **SQP 2012**

As the magnetic field is uniform along the positive z-axis, therefore no change in the magnetic flux through the conducting cylinder.

Thus no current will be induced on the surface of it.

Therefore, direction of induced current on the surface of cylinder, as seen from the z-axis will be zero.

Thus (a) is correct option.

15. If a wire of length 2 m is moving with a velocity of $1\,\text{m–s}^{-1}$ perpendicular to a magnetic field of 0.5 T, then E.M.F. induced in the wire will be

(a) 0.2 V (b) 0.5 V

(c) 1 V (d) 2 V

Ans : **Main 2011**

Length of wire, $l = 2\,\text{m}$

Velocity of wire, $v = 1\,\text{m–s}^{-1}$

Magnetic field, $B = 0.5\,T$

E.M.F. induced in the wire,

$$E = Bvl$$
$$= 0.5 \times 1 \times 2$$
$$= 1\,\text{Volt}$$

Thus (c) is correct option.

16. A metallic rod of length l is placed normal to the magnetic field B and revolved in a circular path about one of the ends with angular speed ω. The potential difference across the ends will be

(a) $B\omega^2 l$ (b) $= \frac{1}{2}B\omega l$

(c) $\frac{1}{2}B\omega l^2$ (d) $= \frac{1}{8}B\omega^3 l$

Ans : **Main 2005**

Given Length of rod $= l$

Magnetic field $= B$

and Angular speed $= \omega$

Change in magnetic flux linked with the rod when it rotates in circular path,

$$d\phi = B \times A$$
$$= B \times \pi l^2$$

and time-taken to complete one-revolution,

$$dt = \frac{2\pi}{\omega}$$

Therefore, induced E.M.F. in the metallic rod,

$$E = \frac{d\phi}{dt} = \frac{B \times \pi l^2}{\frac{2\pi}{\omega}}$$
$$= \frac{1}{2}B\omega l^2$$

Thus (c) is correct option.

17. A 2 m long solenoid with radius 2 cm and 2000 turns has a another solenoid of 1000 turns wound closely near its mid-point. The mutual inductance of solenoids is

(a) 0.8 mH (b) 1.6 mH

(c) 3.2 mH (d) 6.4 mH

Ans : **SQP 2008**

Length of each solenoid, $l = 2\,\text{m}$

Radius of first solenoid, $r = 2\,\text{cm} = 0.02\,\text{m}$

No. of turns in first solenoid, $N_1 = 2000$

No. of turns in second solenoid, $N_2 = 1000$

NODIA

Magnetic moment associated with the coil is,

$$m = NIA = NI \times \pi r^2$$
$$= 100 \times 7.0 \times \frac{22}{7} \times (1.0 \times 10^{-2})^2$$
$$= 0.22\ \text{Am}^2$$

1. The stable equilibrium corresponds to $\vec{m}$ parallel to $\vec{B}$ The potential energy is then minimum.
$$U_{\min} = -mB\cos 0^\circ$$
$$= -0.22 \times 0.2 \times 1$$
$$= -0.044\ \text{J}$$
2. The unstable equilibrium corresponds to $\vec{m}$ anti-parallel to $\vec{B}$. The potential energy is then maximum.
$$U_{\max} = -mB\cos 180^\circ$$
$$= -0.22 \times 0.2 \times (-1)$$
$$= +0.044\ \text{J}$$

132. A short bar magnet placed with its axis at 30° experiences a torque of 0.016 Nm in an external field of 800 G.

1. What is the magnetic moment of the magnet?
2. What is the work done by an external force in moving it from its most stable to most unstable position?
3. What is the work done by the force due to the external magnetic field in the process mentioned in part (2)?
4. The bar magnet is replaced by a solenoid of cross-sectional area $2 \times 10^{-4}\ \text{m}^2$ and 1000 turns, but the same magnetic moment. Determine the current flowing through the solenoid.

Ans : **Main 2014**

1. Given,
$$\theta = 30^\circ$$
$$B = 800\ \text{G} = 800 \times 10^{-4}\ \text{T}$$
$$\tau = 0.016\ \text{Nm}$$
Magnetic moment,
$$m = \frac{\tau}{B\sin\theta}$$
$$= \frac{0.016}{800 \times 10^{-4} \times \sin 30^\circ}$$
$$= 0.40\ \text{Am}^2$$
2. For most stable position, $\theta = 0^\circ$ and for most unstable position $\theta = 180^\circ$. So the required work done by the external force,
$$W = -mB(\cos 180^\circ - \cos 0^\circ)$$
$$= 2\ \text{mB}$$
$$= 2 \times 0.40 \times 800 \times 10^{-4}$$
$$= 0.064\ \text{J}$$
3. Here the displacement ant the torque due to the magnetic field are in opposition. So the work done by the magnetic field due to the external magnetic field is
$$W_B = 0.064\ \text{J}$$
4. Given,
$$A = 2 \times 10^{-4}\ \text{m}^2$$
$$N = 1000$$
Magnetic moment of solenoid,
$$m_s = m = 0.40\ \text{Am}^2$$
But, $m_s = NIA$
Hence, Current, $I = \frac{m_s}{NA}$
$$= \frac{0.40}{1000 \times 2 \times 10^{-4}}$$
$$= 2\ \text{A}$$

CASE BASED QUESTIONS

133. Mr. Rajesh the chief development officer, in southern railway went on an official tour to attend a seminar on fast moving trains. He met his friend Ontosaki in Tokyo after he finished his seminar there. His friend explained to Rajesh how Japanese people are concentrating on energy conservation and saving of fossil fuels using Maglev trains. Mr. Rajesh travelled from Tokyo to Osaka in Maglev train and found that sound is less, travelling is smooth and understood in what way we are lagging behind Japanese in mass transporting systems. This works on the principle of Meissner's effect.

(i) What is Meissner's effect?

(ii) Write the value of magnetic permeability for perfect diamagnetism.

Ans :

(i) When a superconductor is cooled in a magnetic field below its critical temperature the magnetic field lines are expelled showing diamagnetic property. This is called Meissner's effect.

(ii) Diamagnetic materials have magnetic permeability of less than 1.

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Therefore, current induced in the circuit,

$$I = \frac{\text{Induced e.m.f.}}{\text{Resistance of circuit}}$$

$$= \frac{\frac{\Delta\phi}{\Delta t}}{R} = \frac{\Delta\phi}{R\Delta t}$$

We also know that total electric charge that passes any point in the circuit during the time,

$$\Delta t(Q) = I \cdot \Delta t$$

$$= \frac{\Delta\phi}{R\Delta t} \times \Delta t$$

$$= \frac{\Delta\phi}{R}$$

Thus (b) is correct option.

21. A solenoid having self-inductance of 8 H is connected to a battery through a switch. When the switch is closed, current through the solenoid increases from 0 A to 5 A in 0.2 s.

(i) Magnitude of the emf induced in the solenoid is

(a) 2 V (b) 20 V

(c) 200 V (d) 2000 V

(ii) If the switch is now opened, magnitude of the emf induced in the solenoid will be

(a) same as in part (i)

(b) more than that in part (i)

(c) less than that in part (i)

(d) zero

Ans : **Main 2022 Sem-I**

Given, $L = 8\,\text{H}$,

$$\Delta I = 5 - 0 = 5\,\text{A},\ \Delta t = 0.2\,\text{s}$$

(i) (c) 200 V

Magnitude of induced

$$\text{emf } (e) = \left| -L \cdot \frac{\Delta I}{\Delta t} \right|$$

$$= 8 \times \frac{5}{0.2} = 200\ \text{V}$$

(ii) (b) more than that in part (i)

As $e \propto \frac{1}{\Delta t}$

$$\frac{e_0}{e_c} = \frac{\Delta t_c}{\Delta t_0} > 1$$

$$e_0 > e_c$$

22. With reference to a transformer, choose the correct option.

(i) The principle of its working is

(a) self-induction

(b) mutual induction

(c) magnetic effect of current

(d) chemical effect of current

(ii) In an actual transformer,

(a) output voltage is always equal to the input voltage

(b) output current is always equal to the input current

(c) output power is always equal to the input power

(d) output power is always less than input power

(iii) For a step-up transformer,

(a) output voltage is greater than input voltage

(b) output current is greater than input current

(c) output power is greater than input power

(d) number of turns in primary coil is greater than that in secondary coil

Ans : **Main 2022 Sem-I**

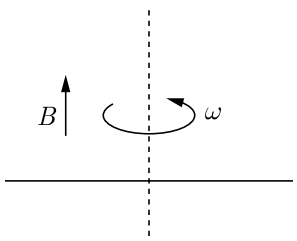
(i) (b) Mutual induction

(ii) (d) Output power is always less than input power

(iii) (a) Output voltage is greater than input voltage

NODIA

23. A conducting rod of length $2l$ is rotating with a constant angular speed ω about its perpendicular bisector as shown in the figure. A uniform magnetic field B exists parallel to the axis of rotation. The e.m.f. induced between two ends of the rod is



(a) zero (b) $B\omega l^2$

(c) $\frac{1}{2}B\omega l^2$ (d) $\frac{1}{8}B\omega l^2$

Ans : **Main 2016, 2012**

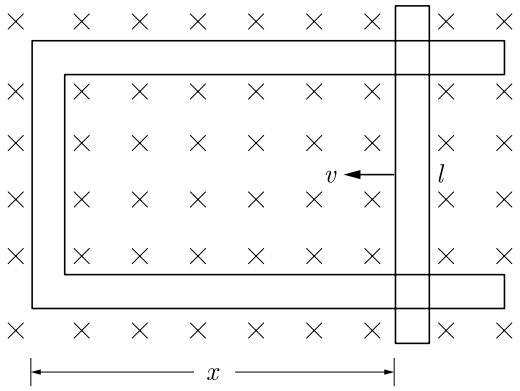
Length of rod $= 2l$

Angular speed $= \omega$

and Uniform magnetic field $= B$

Ans : **Main 2009**

Suppose a rod of length 'l' moves with velocity V inward in the region having uniform magnetic field B. Initial magnetic flux enclosed in the rectangular space is $\phi = |B|lx$.



As the rod moves with velocity,

$$v = \frac{dx}{dt}$$

Using Lenz's law,

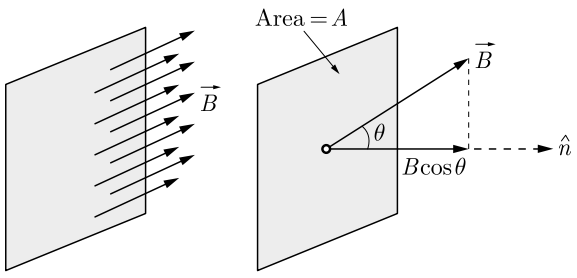
$$e = -\frac{d\phi}{dt} = -\frac{d}{dt}(Blx) = Bl\left(-\frac{dx}{dt}\right)$$

Hence, $e = Blv$

72. Define the term magnetic flux. Is it a scalar or vector quantity?

Ans : **Main 2021**

The magnetic flux through any surface placed in a magnetic field is the total number of magnetic lines of force crossing this surface normally.



Magnetic Flux Through a Given Surface Area

As shown in figure, if the magnetic field $\vec{B}$ makes an angle θ with the normal drawn to a surface area A, then the flux linked with this area is,

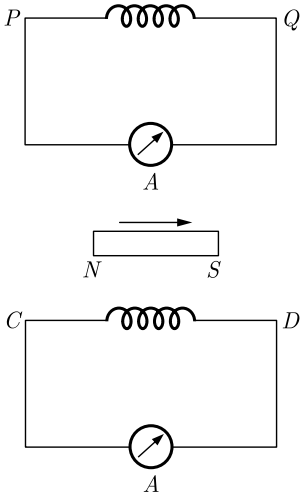
ϕ = Normal component of B × Surface area

$= B\cos\theta \times A$

$\phi = BA\cos\theta = \vec{B} \cdot \vec{A}$

Here the direction of vector $\vec{A}$ is the direction of the outward drawn normal to the surface. Clearly, magnetic flux is a scalar quantity.

73. A bar magnet is moved in the direction indicated by the arrow between two coils PQ and CD. Predict the directions of induced current in each coil.



Ans : **Comp 2021, 2009**

From the figure, it is clear that North pole of the magnet is moving away from coil PQ, so the direction of current at end Q will flow in such a way that it will oppose the away moment of North pole, so it has to act as South pole. Hence, the direction of current will be anti-clockwise. Again, the South pole is approaching towards coil CD, so end C of the coil will act as South pole (to oppose the approaching of South pole). Hence, the direction of current will be clockwise.

74. Two concentric circular coils C_1 and C_2 radius r_1 and r_2 ($r_1 << r_2$) respectively are kept coaxially. If current is passed through C_2, then find an expression for mutual inductance between the two coils.

Ans : **Main 2017**

Let current I_2 passes through the coil C_2.

Magnetic field at centre due to current loop C_2

$$B_2 = \frac{\mu_0 N_2 I_2}{2r_2}$$

N_2 = number of turns in coil C_2.

Magnetic flux linked with coil C_2

$$\phi_1 = N_1 B_2 A_1$$

$$\phi_1 = N_1\left(\frac{\mu_0 N_2 I_2}{2r_2}\right)(\pi r_1^2)$$

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30. On what factors does the magnitude of the emf induced in the circuit due to magnetic flux depend?

Ans : **Main 2025**

Depends on the time rate of change in magnetic flux (or simply change in Magnetic Flux)

$$|\varepsilon| = \frac{\Delta\phi}{\Delta t}$$

31. Write Lenz's law of electromagnetic induction.

Ans : **Main 2016, 2013**

Lenz's Law states that the direction of induced current in a circuit is such that it opposes the cause or the change which produces it. i.e., it opposes the change in magnetic flux.

$$e = \frac{-d\phi}{dt}$$

32. Why is the core of a transformer laminated?

Ans : **Main 2018**

The alternating magnetic flux induces eddy currents in iron core of transformer and because of this, the loss of energy takes place in the form of heat. To minimise this loss, transformer cores are laminated.

33. What is an ideal transformer?

Ans : **Main 2016**

An ideal transformer is an imaginary transformer which has no copper losses (no winding resistance), no iron loss in core and no leakage flux. In other words, an ideal transformer gives output power exactly equal to the input power.

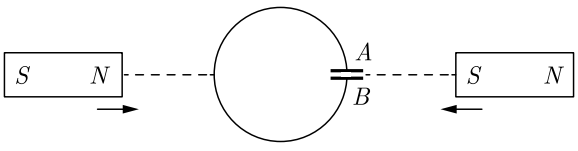
34. How can the self-inductance of a given coil having N number of turns, area of cross-section A and lengths l be increased?

Ans : **Main 2024**

The self-inductance can be increased by the help of electric fields. It does not depend on the current through circuit but depends upon the permeability of material from which the core is made up off.

35. Predict the polarity of the capacitor in the situation described below :

Ans : **Main 2011, 2008**



The polarity of plate A will be positive with respect to plate B in the capacitor.

36. Derive dimension and SI unit of magnetic flux.

Ans : **Main 2010**

$$\phi = B.A$$

Since, $$B = \frac{F}{qv\sin\theta}$$

$$\phi = \frac{F.A}{qv\sin\theta}$$

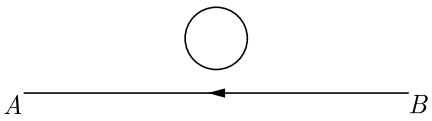
$\sin\theta$ is the dimensionless quantity.

$$\phi = \frac{[\mathrm{M^1L^1T^{-2}}][\mathrm{L^2}]}{[\mathrm{AT}][\mathrm{LT^{-1}}]}$$
$$= [\mathrm{M^1L^2T^{-2}A^{-1}}]$$

The S.I. Unit of magnetic flux is weber (wb).

37. The electric current flowing in a wire in the direction from B to A decreasing. Find out the direction of the induced current in the metallic loop kept the wire as shown in the figure.

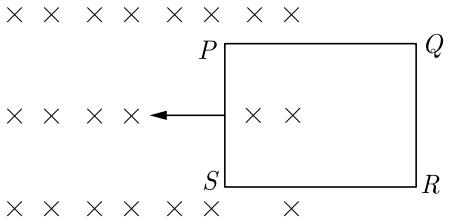
Ans : **Main 2018**



According to Lenz's law, the direction of induced current will oppose the cause of its production. So, the current in loop will induce in such a way that it will support the current flowing in the wire i.e., in the same direction. So, the direction of current in the loop will be clockwise.

38. The closed loop $PQRS$ of wire is moved into a uniform magnetic field at right angles to the plane of the paper as shown in the figure. Predict the direction of the induced current in the loop.

Ans : **Comp 2020**



Since, magnetic flux increasing when the loop moves into uniform magnetic field. So, the induced current should oppose this increase. Thus, flow will be from $QPSRQ$. i.e., anti-clockwise.

NODIA

Induced E.M.F. in a small element dx of the rod from its centre $= Bvdx$.

Therefore, induced E.M.F. between the two ends of the rod,

$$E = \int_{-l}^{+l} Bvdx$$
$$= \int_{-l}^{+l} B\omega x dx$$
$$= B\omega\left[\frac{x^2}{2}\right]_{-l}^{+l}$$
$$= B\omega\left[\frac{l^2}{2} - \frac{(-l)^2}{2}\right] = 0$$

Thus (a) is correct option.

ASSERTION AND REASON

24. **Assertion :** Lenz's law violates the principle of conservation of energy.

Reason : Induced emf always opposes the change in magnetic flux responsible for its production.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **Main 2018**

Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

Lenz's law (that the direction of induced emf is always such as to oppose the change that cause it) is direct consequence of the law of conservation of energy.

Thus (a) is correct option.

25. **Assertion :** Faraday's laws are consequence of conservation of energy.

Reason : In a purely resistive ac circuit, the current legs behind the emf in phase.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **SQP 2015**

Assertion is correct but Reason is incorrect.

In purely resistive circuit, the current and emf are in the same phase.

Thus (c) is correct option.

26. **Assertion :** An emf $\vec{E}$ is induced in a closed loop where magnetic flux is varied. The induced $\vec{E}$ is not a conservative field.

Reason : The line integral $\vec{E} \cdot d\vec{l}$ around the closed loop is non-zero.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **Main 2012**

Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

According to Faraday's law of electromagnetic induction

$$\int \vec{E} \cdot d\vec{\ell} = -\frac{d\phi}{dt}$$

So, (E) is non-conservative field as in conservative field line integral over a closed loop is zero.

Thus (a) is correct option.

ONE MARK QUESTIONS

27. What is meant by "Motional emf'?

Ans : **Main 2023**

The emf which is produced due to the motional of a conductor Rower is motional emf.

28. How is magnetic flux linked with the armature coil changed in a generation?

Ans : **Main 2016**

The direction of flow of current in resistance R get changed alternatively after every half cycle. Thus, AC is produced in coil.

29. Give any one reason why efficiency of a transformer is always less than 1.

Ans : **Main SQP 2023**

Practically there are numerous factors leading to energy loss in a transformer and hence, the efficiency is always less than one

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disc begins to increase. This sets up eddy current in the disc in the same direction as that of the electromagnetic current. Thus, if the upper surface of electromagnetic acquires N-polarity, the lower surface of the disc also acquires N-polarity. As, same magnetic poles repel each other, the light metallic disc is thrown up.

49. Give the three possible ways of producing an induced emf in a coil giving an example in each case.

Ans : **SQP 2010**

As $\phi = BA\cos\theta$, so the magnetic flux linked with a loop can be changed and hence induced emf can be produced by three methods :

1. By changing the magnetic field B e.g., by moving a bar magnet towards or away from a closed coil.
2. By changing the area of a closed loop e.g., by moving one arm of a rectangular conductor in a perpendicular magnetic field.
3. By changing in relative orientation θ of the loop and the magnetic field e.g., by rotating a closed coil about an axis perpendicular to the magnetic field.

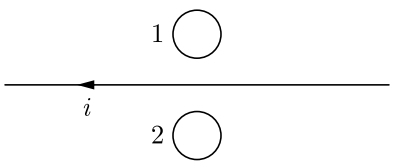
50. Define mutual inductance between two long coaxial solenoids. Find out the expression for the mutual inductance of inner solenoid of length l having the radius r_1 and the number of turns n_1 per unit length due to the second outer solenoid of same length and n_2 number of turns per unit length.

Ans : **Main 2025**

The phenomenon of generation of induced emf in a long solenoid due to a change of current in another neighbouring coaxial solenoid is known as mutual induction. The mutual induction for the pair of the solenoid is

$$M = \frac{\mu_0 N_1 N_2 A}{l}$$

51. Predict the direction of induced current in metal rings 1 and 2 when current i in the wire is steadily decreasing?

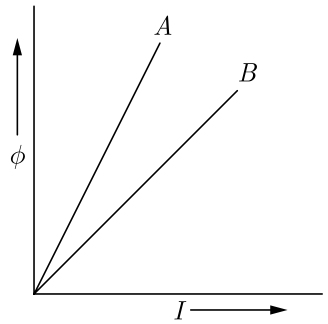


Ans : **Main 2019**

Current in the wire is steadily decreasing, so the induced current in rings 1 and 2 will flow in such a way that it opposes the decreases of current.

So, it will flow in same direction. Now, from the figure. It is clear that the direction of induced current in ring 1 is clockwise and ring 2 is anti-clockwise.

52. A plot of magnetic flux (ϕ) versus current (I), is shown in the figure for two inductors A and B. Which of the two has large value of self-inductance?



Ans : **SQP 2005**

As we know that,

$$\phi = LI \ = \frac{\phi}{I} = L$$

The slope of $\frac{\phi}{I}$ of straight line is equal to self-inductance L. It is larger for inductor A, therefore inductor A has longer value of self inductance L.

53. State the Faraday's law's of electromagnetic induction.

Ans : **SQP 2008**

On the basis of his experiment, Faraday gave the following two laws :

1. Whenever magnetic flux linked with a circuit changes, an emf is induced in it which lasts, so long as change in flux continuous.
2. The emf induced in loop or closed circuit is directly proportional to the rate of change of magnetic flux linked with the loop

   i.e., $e \propto \frac{d\phi}{dt}$

   or $e = N\frac{d\phi}{dt}$

   where, $N =$ number of turns in the coil

54. How does one understand this motional emf by invoking the Lorentz force acting on the free charge carriers of the conductor? Explain.

Ans : **SQP 2008**

Suppose any arbitrary charge 'q' in the conductor of length l moving inward in the field as shown in figure, the charge q also moves with velocity v in the magnetic field B.

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TWO MARKS QUESTIONS

39. A straight wire extending from East to West falls with a speed v at right angles to the horizontal component of the Earth's magnetic field. Which end of the wire would be at the higher electrical potential and why?

Ans : SQP 2016

The induced emf is produced because component H will be interchanged and higher potential will be at East side of wire.

40. Briefly explain the following term Self-induction

Ans : SQP 2018

Self-induction is the property of a coil by virtue of which, the coil opposes any change in the current flowing through it by inducing an emf in itself. It is also called inertia of electricity due to this property.

41. Explain why a blue coloured spark is often seen in a switch when a circuit containing an electric iron/geyser is switched off.

Ans : SQP 2023

While switching off, the terminals come close to each other. It produces very high induced emf. Due to this high emf, charges move from one end to the other end of the switch. This spark appears blue.

42. What causes the core of a transformer to get heated up under operation?

Ans : Main 2024

When a metallic wire moves in a uniform magnetic field, due to change in magnetic flux of the wire, emf is induced between two ends of the wire.

The core of a transformer gets heated up due to eddy current and copper losses.

43. When an electric current is passed through a wire or a coil, a magnetic field is produced. Is the reverse phenomenon possible i.e., can a magnetic field produce an electric current? Explain with the help of an appropriate example.

Ans : Main 2023

If the magnetic flux linked with a coil changes with time, then induced current is produced in the coil. For example, AC generators and electrical transformers work on the principle of electromagnetic induction.

44. Define mutual inductance. Write its SI unit.

Ans : SQP 2007

Mutual inductance of two coils in the magnetic flux linked with the secondary coil when a unit current flows through the primary coil,

i.e., $\phi_2 = MI_1$ or $M = \frac{\phi_2}{I_1}$

SI unit of mutual inductance is Henry (H).

45. Name any two types of energy losses in a transformer. State how any one of them can be minimised.

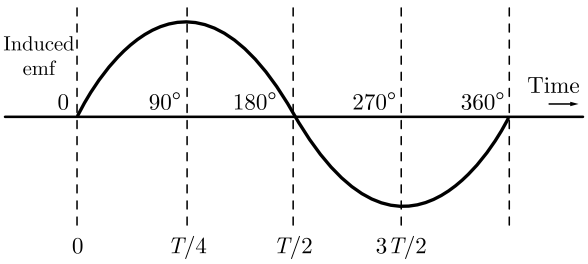
Ans : SQP 2014, 2011

Iron loss It is the energy loss in the form of heat in the iron core of the transformer. This occurs because of the presence of eddy current in iron core.

Hysteresis loss This is the loss of energy due to repeated magnetisation and demagnetisation of the iron core when AC is fed to it. The loss can be minimised by using a magnetic material which has low hysteresis loss.

46. Show the variation of the emf generated versus time as the armature is rotated with respect to the direction of the magnetic fields.

Ans : Main 2008



47. What is motional emf? State any two factors on which it depends?

Ans : Main 2018

When a conducting rod is moved through constant magnetic field, then emf is generated by a conducting rod. This emf is called motional electromotive force, because it arises due to motion of charges through a magnetic field. The expression for motional emf is given by $e = Bvl$. Therefore, the motional emf depends upon the magnetic field, speed and length of a conductor.

48. A light metal disc on the top of an electromagnet is thrown up as the current is switched on. Why? give reason.

Ans : SQP 2013, 2010

When the current begins to grow through the electromagnet, the magnetic flux through the

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59. Deduce the expressions for the power delivered by the source and the power dissipated as Joule heat.

Ans : **Main 2025**

Energy Consideration : If R is resistance of the rectangular loop, which does not change with the motion of the loop, then current I in the loop is

$$I = \frac{e}{R} = \frac{Blv}{R}$$

The magnitude of force on arm KL is

$$F = BIl$$

$$= B\left(\frac{Blv}{R}\right)l = \frac{B^2l^2v}{R}$$

Power required to push the loop

$$P = Fv$$

$$= \frac{B^2l^2v \times v}{R} = \frac{B^2l^2v^2}{R}$$

This is the energy spent/sec., mechanically in moving the loop, which is dissipated as Joule's heat loss/sec.

$$P = I^2R = \left(\frac{Blv}{R}\right)^2$$

$$R = \frac{B^2l^2v^2}{R}$$

Thus, mechanical energy needed to move the arm KL is converted into electrical energy (induced e.m.f.) and then to thermal energy.

60. The SI unit of coefficient of inductance is henry. Using any defining equation for L or M show that $1\,\text{H} = 1\,\Omega\text{-s}$

Ans : **Main 2007, 2003**

$$|\varepsilon| = \frac{-\Delta\phi}{\Delta t} = -M\frac{\Delta i}{\Delta t} = -M\frac{di}{dt}$$

where, $|\varepsilon|$ = magnitude of induced emf

$\Delta\phi$ = change in magnetic flux

Δt = during of change in flux

M = coefficient of mutual inductance

So, $$M = \frac{|\varepsilon|}{\frac{di}{dt}}$$

$$1 \text{ henry} = \frac{\text{volt}}{\frac{\text{ampere}}{\text{second}}} \quad \text{[by writing units]}$$

$$1 \text{ henry} = 1\,\Omega\text{-s.}$$

[taking all the values as unity]

$$\left[\text{ohm} = \frac{\text{volt}}{\text{ampere}}\right]$$

THREE MARKS QUESTIONS

61. State Lenz's law. A metallic rod held horizontally along east-west direction, is allowed to fall under gravity. Will there be an emf induced at its ends ? Justify your answer.

Ans : **Comp 2016**

Lenz's Law states that the direction of induced current in a circuit is such that it opposes the cause or the change which produces it. i.e., it opposes the change in magnetic flux.

$$e = \frac{-d\phi}{dt}$$

Yes, emf will be induced in the rod as there is change in magnetic flux.

When a metallic rod held horizontally along East-west direction, is allowed to fall freely under gravity i.e., fall from North to south, the intensity of magnetic lines of the Earth's magnetic field changes through it, i.e., the magnetic flux changes and hence emf induced in it.

62. Starting from the expression for the energy $W = \frac{1}{2}LI^2$, stored in a solenoid of self-inductance L to build up the current I, obtain the expression for the magnetic energy in terms of the magnetic field B, area A and length l of the solenoid having n number of turns per unit length. Hence, show that the energy density is given by $B^2/2\mu_0$.

Ans : **Main 2013**

Energy stored in the magnetic field,

$$W = \frac{1}{2}LI^2 = \frac{1}{2}\frac{\alpha_0 N^2 A}{L} \cdot \frac{B^2L^2}{\alpha_0^2 N^2}$$

$$= \frac{\alpha_0^2}{2\alpha_0}(AL)^2$$

$$\left[\text{since, } L = \frac{\alpha_0 N^2 A}{L}, B = \frac{\alpha_0 NL}{L}\right]$$

energy density,

$$u_B = \frac{\text{Energy}}{\text{Volume}}$$

$$= \frac{B^2}{2\mu_0} \text{ [Hence, } B = AL\text{]}$$

63. State a rule to determine the direction of current induced due to the motion of a conductor in a perpendicular magnetic field.

Ans : **Main 2015**

Fleming's right hand rule gives the direction of induced current set up in a conductor moving perpendicular to a magnetic field and can be stated as follows:

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The Lorentz force on the charge 'q' is F.

$$F = qvB \text{ and its direction is downwards}$$

So, work done in moving the charge 'q' along the conductor of length l.

$$W = F.l$$

$$W = qvBl$$

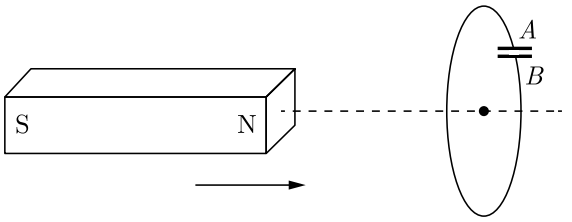
Since emf is the work done per unit charge,

Hence, $$e = \frac{W}{q}$$

$$= Blv$$

This equation gives emf induced across the rod.

55. In the given figure, a bar magnet is quickly moved towards a conducting loop having a capacitor. Predict the polarity of the plates A and B of the capacitor.



Ans : **Main 2011**

The North pole is approaching the magnet, so the induced current in the face of loop viewed from left side will flow in such a way that it will behave like North pole, so south pole developed in loop when viewed from right hand side of the loop. The flow of induced current is clockwise, hence A acquires positive polarity and B requires negative.

56. How does the mutual inductance of a pair of coils change, when

1. distance between the coils is increased and
2. number of turns in the coils is increased?

Ans : **Comp 2011, 2007**

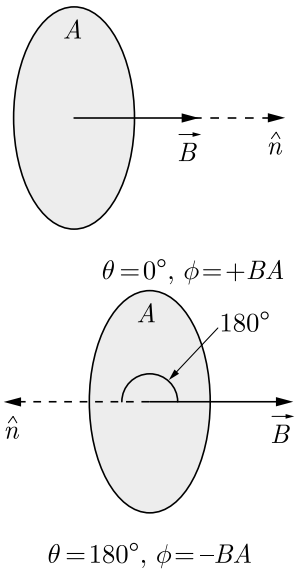
1. $\phi \cdot A = MI$, with the increase in the distance between the coils the magnetic flux linked with the secondary coil decreases and hence, the mutual inductance of the two coils will decreases with the increase of separation between them.
2. Mutual inductance of two coils can be found out by $M = \mu_0 N_1 N_2\ Al$, i.e.,

   $M \propto N_1 N_2$, so, with the increase in number of turns mutual inductance increases.

57. When is the magnetic flux taken as positive and negative?

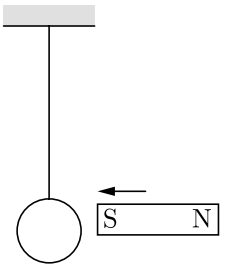
Ans : **Main 2020**

A normal to a plane can be drawn from either side. If the normal drawn to a plane points out in the direction of the field, then $\theta = 0°$ and the flux is taken as positive. If the normal points in the opposite direction of the field, then $\theta = 180°$ and the flux is taken as negative.



(a) Positive Flux **(b) Negative Flux**

58. When a magnet is moved towards a suspended wire loop as shown in figure then evaluate the direction of induced current in loop. State the law used by your for this evaluation.



Ans : **Main 2019**

When south pole of magnet moves towards the coil, the induced current flows clockwise in the coil when seen from its right hand side. Lenz's law evaluate the direction of induced current in loop.

Lenz's law states that the direction of induced current in a circuit is such that it opposes the cause or the change which produces it.

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decreases. Therefore, mutual inductance will be decreased.

(ii) Mutual inductance for a pair of coil is given by

$$M = K\sqrt{L_1 L_2}$$

where, $L = \frac{\mu N^2 A}{l}$ and L is called self inductance.

Therefore, when the number of turns in each coil increases, the mutual inductance also increases.

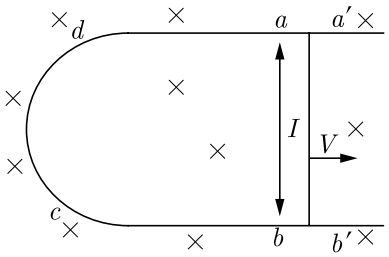
(iii) When a thin iron sheet is placed between the two coils, the mutual inductance increases because

$M \propto$ permeability. The permeability of the medium between coils increases.

68. A rod of length l is moved horizontally with a uniform velocity v in a direction perpendicular to its length through a region in which a uniform magnetic field is acting vertically downward. Derive the expression for the emf induced across the ends of the rod.

Ans : **Main 2016**

Consider a straight conductor moving with velocity v and U shaped conductor placed in perpendicular magnetic field as shown in the figure.



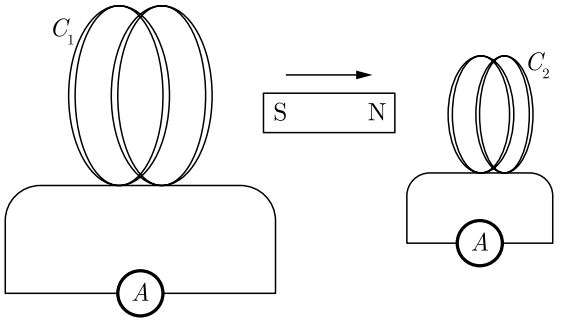
Let conductor shifts from ab to $a'\ b'$ in time dt, then change in magnetic flux

$$d\phi = B \times \text{change in area}$$
$$= B \times (\text{area } a'b'ab)$$
$$= B \times (l \times v\, dt)$$
$$\frac{d\phi}{dt} = Bvl$$

Hence, induced emf

$$|\varepsilon| = \frac{d\phi}{dt} = Bvl$$

69. A magnet is quickly moved in the direction indicated by an arrow between two coils C_1 and C_2 as shown in the figure. What will be the direction of induced current in each coil as seen from the magnet? Justify your answer.



Ans : **Main 2009, 2006**

According to Lenz's law, the direction of induced current is such that it opposes the relative motion between coil and magnet.

As N-pole of the magnet is moving away from the coil C the near face of coil C_1 will become S -pole, so the direction of current in coil C_1, will be clockwise.

The near face of coil C_2 will also become S-pole to oppose the approach of magnet, so the current in coil C_2 will also be clockwise.

70. In an experimental arrangement of two coils C_1 and C_2 placed coaxially parallel to each other, find out the expression for the emf induced in the coil C_1 (of N_1 turns) corresponding to the change of current I_2 in the coil C_2 (of N_2 turns)

Ans : **Main 2024**

Let ϕ_1 be the flux through coil C_1 (of N_1 turns) when current in coil C_2 is I_2. Then, we have

$$N_1\phi_1 = MI_2 \quad ...(1)$$

For current varying with time.

$$\frac{d(N_1\phi_1)}{dt} = \frac{d(MI_2)}{dt} \quad ...(2)$$

Since induced emf in coil C_1 is given by

$$\varepsilon_1 = -\frac{d(N_1\phi_1)}{dt}$$

Hence, From $(2) - \varepsilon_1 = M\left(\frac{dI_2}{dt}\right)$

$$\varepsilon_1 = -m\frac{dI_2}{dt} \quad [\text{from } (1)]$$

It shows that varying current in a coil induces emf in the neighbouring coil.

71. A rod of length l is moved horizontally with a uniform velocity 'V' in a direction perpendicular to its length through a region in which a uniform magnetic field is acting vertically downward. Derive the expression for the emf induced across the ends of the rod.

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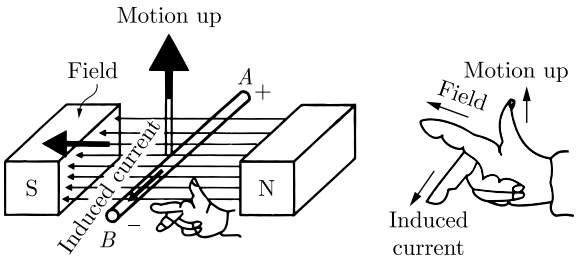


Fleming's Right Hand Rule

If we stretch the thumb and the first two fingers of our right hand in mutually perpendicular directions and if the forefinger points in the direction of the magnetic field, thumb in the direction of motion of the conductor; then the central finger points in the direction of current induced in the conductor.

This rule is also called the dynamo or generator rule and has wide practical applications.

64. Name and define the SI and CGS units of magnetic flux. Write the relation between them.

Ans : **Main 2020**

SI Unit of Magnetic Flux : The SI unit of magnetic flux is weber (Wb). One weber is the flux produced when a uniform magnetic field of one tesla acts normally over an area of $1\,m^2$.

$$1 \text{ weber} = 1 \text{ tesla} \times 1 \text{ metre}^2$$

or $$1\ Wb = 1\ Tm^2$$

CGS Unit of Magnetic Flux : The CGS unit of magnetic flux is Maxwell (Mx). One maxwell is the flux produced when a uniform magnetic field of one gauss acts normally over an area of $1\,cm^2$.

$$1 \text{ maxwell} = 1 \text{ gauss} \times 1\ cm^2$$

$$1\ Mx = 1\,G\,cm^2$$

Relation between Weber and Maxwell

$$1\ Wb = 1\,T \times 1\,m^2$$

$$= 10^4\,G \times 10^4\,cm^2$$

$$1\ Wb = 10^8 \text{ maxwell}$$

65. Derive the expression for maximum value of the induced emf and state the rule that gives the direction of the induced emf.

Ans : **Main 2014, 2011**

Let at any instant coil magnetic flux linked with the armature coil is G. and $\theta = \omega t$ is the angle made by area vector of coil with magnetic field.

$$\phi = NBA\cos\theta = NBA\cos\omega t$$

$$\frac{d\phi}{dt} = -NBA\omega\sin\omega t$$

$$\frac{d\phi}{dt} = NBA\omega\sin\omega t$$

By Faraday's law of EMI,

$$e = \frac{-d\phi}{dt}$$

Induced emf in coil is given by

$$e = NBA\omega\sin\omega t$$

$$e = e_0\sin\omega t$$

where, $e_0 = NBA\omega$

$= $ peak value of induced emf.

The mechanical energy spend in rotating the coil in magnetic field appears in the form of electrical energy.

66. How does the mutual inductance of a pair of coils change when

(i) distance between the coils is increased and

(ii) number of turns in the coils is increased?

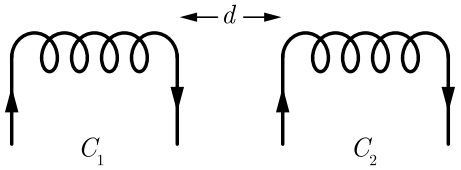
Ans : **Main 2005**

(i) Mutual inductance decreases.

(ii) Mutual inductance increases.

Concept

(i) If distance between two coils is increased as shown in figure.



It causes decrease in magnetic flux linked with the coil C_2. Hence, induced emf in coil C_2 decreases by relation $\varepsilon_2 = \frac{-d\phi_2}{dt}$. Hence, mutual inductance decreases.

(ii) From relation $M_{21} = \mu_0 N_1 N_2\ AI$, if number of turns in one of the coils or both increases, means mutual inductance will increase.

67. How is the mutual inductance of a pair of coils affected when

(i) separation between the coils is increased?

(ii) the number of turns in each coil is increased?

(iii) a thin iron sheet is placed between the two coils, after factors remaining the same?

Ans : **Main 2025**

(i) When the relative distance between the coil is increased, the leakage of flux increases which reduces the magnetic coupling of the coils. So magnetic flux linked with all the turns

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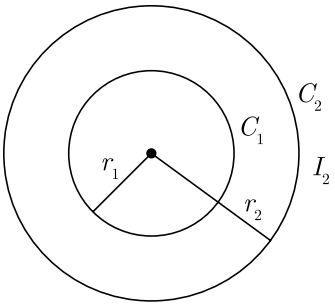


But, $\phi = \mu I_2$

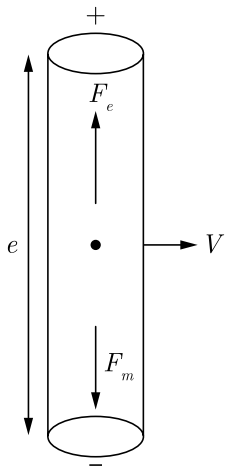
$$MI_2 = \frac{\mu_0 N_1 N_2 I_2}{2r_2}\pi r_1^2$$

$$M = \frac{\mu_0 \pi N_1 N_2 r_1^2}{2r_2}$$

75. How does one understand this motional emf by invoking the Loranz force acting on the free charge carriers of the conductor? Explain.

Ans : **Main 2014**

During motion, free $\vec{e}$ are shifted at one end due to magnetic force so due to polarisation of rod electric field is produced which applies electric force on free $\vec{e}$ on opposite direction.



At equilibrium of Lorenz force,

$$\begin{aligned} F_e + F_m &= 0 \\ qE + q(v \times B) &= 0 \\ E &= -v \times B \\ &= B \times v \\ |E| &= |Bv \sin 90| \\ \frac{dv}{dr} &= Bv \\ P_D &= Bvl \end{aligned}$$

76. A metallic rod of length L is rotated with angular frequency of ω with one end hinged at the centre and the other and at the circumference of a circular metallic ring of radius L, about an axis passing through the centre and perpendicular to the plane of the ring. A constant and uniform magnetic field B parallel to the axis is present everywhere. Deduce the expression for the emf between the centre and the metallic ring.

Ans : **SQP 2006, 2004**

Angular velocity of rod,

$$\omega = \frac{2\pi}{T}$$

where, $T =$ time period

Hence, charge in flux in one revolution

$$\begin{aligned} &= BA \\ &= B(\pi L^2) \end{aligned}$$

According to Faraday's law of EMI, magnitude of induced emf

$$\begin{aligned} \varepsilon &= \frac{\Delta\phi}{\Delta T} \\ &= \frac{B\pi L^2}{T} \\ &= \frac{B\pi L^2}{\left(\frac{2\pi}{\omega}\right)} \qquad \left[\text{since } T = \frac{2\pi}{\omega}\right] \\ \varepsilon &= \frac{1}{2}B\omega L^2 \end{aligned}$$

77. A metallic rod of length l and resistance R is rotated with a frequency v, with one and hinged at the centre and the other end at the circumference of a circular metallic ring of radius l, about an axis passing through the centre and perpendicular to the plane of the ring. A constant and uniform magnetic field B parallel to the axis is present everywhere.

(i) Derive the expression for the induced emf and the current in the rod.

(ii) Due to the presence of the current in the rod and of the magnetic field, find the expression for the magnitude and direction of the force acting on this rod.

(iii) Hence, obtain the expression for the power required to rotate the rod.

Ans : **Main 2014**

(i) In the one revaluation change of area, $dA = \pi l^2$

Hence, change of magnetic flux,

$$d\phi = B \cdot dA = Bd,$$

$$A\cos 0^\circ = B\pi l^2$$

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where, A = area of each turn of the solenoid

Total magnetic flux linked with the solenoid

= Flux through each turn

× Total number of turns

$$N\phi = \mu_0 \frac{N}{l} IA \times N \quad ...(2)$$

If, L is coefficient of self-inductance of the solenoid, then

$$N\phi = LI \quad ...(3)$$

From equation (2) and (3), we get

$$LI = \mu_0 \frac{n}{l} IA \times N$$

or $$L = \frac{\mu_0 N^2 A}{l}$$

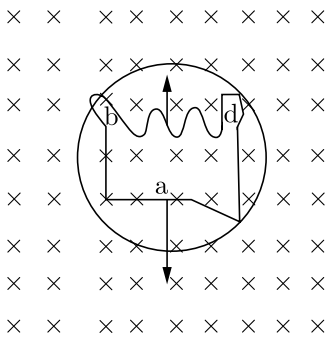
If core of any other magnetic material, μ is placed,

Then, $\mu = \mu_r \ \mu_0$

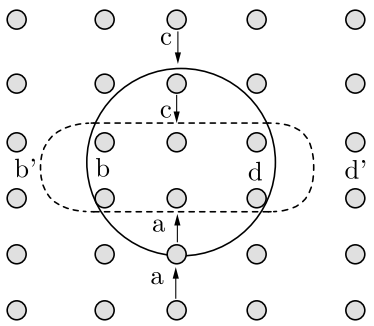
$[\mu_r$ = relative magnetic permeability$]$

Hence, $L = \frac{\mu_r \mu_0 N^2 A}{l}$

83. Use Lenz's law to determine the direction of induced current in the situation described by following figures.



(a)



(b)

(a) A wire of irregular shape turning into a circular shape.

(b) A circular loop being deformed into a narrow straight wire.

Ans : Comp 2014

(a) For the given periphery the area of a circle is maximum. When a coil takes a circular shape, the magnetic flux linked with coil increases, so current induced in the coil will tend to decrease the flux and so will produce a magnetic field upward. As a result the current induced in the coil will flow anti-clockwise i.e., along $adcb$.

(b) For given periphery the area of circle is maximum. When circular coil takes the shape of narrow, straight wire, the magnetic flux linked with the coil decreases, so current induced in the coil will tend to oppose the decrease in magnetic flux, hence it will produce upward magnetic field, so current induced in the coil will flow anti-clockwise i.e., along $a'd'c'b'$.

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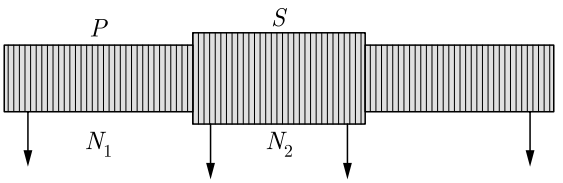
FOUR MARKS QUESTIONS

84. Deduce an expression for the mutual inductance of two long coaxial solenoids but having different radii and different number of turns.

Ans : SQP 2011

Mutual Inductance of two Coaxial Solenoids : Let us consider a long air-cored solenoid P (primary) of length l and area of cross-section A, having N_2 turns he would closely over the central portion of the primary P. Let i_1 be the current in the primary. The magnitude of the magnetic field $\vec{B}$ inside the primary is, in SI unit, given by



The magnetic flux linked with the primary due to the field $\vec{B}$ is also linked with the secondary because the secondary is wound closely over the current portion of the primary. Thus, the magnetic flux linked with each turn of the secondary is

$$\phi_2 = BA = \mu_0 \frac{N_1}{l} i_1 A$$

Where, A is the area of cross-section of the secondary (although it is almost the search as of the primary).

80. Define self-inductance. Obtain the expression for the self-inductance of a solenoid, explaining steps with the help of a diagram.

Ans : **Main 2000**

Self-inductance of a solenoid is associated with the geometry of the coil.

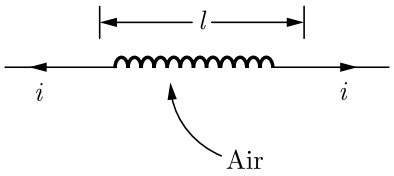
Self-inductance of a coil is equal to the total magnetic flux linked with the coil, when unit current passes through it.

Self-inductance of a coil is equal to the emf induced in coil, when rate of change of current in the coil is 1 A/s.

The SI unit of self-inductance is henry (H).

$$1 \text{ H} = 1 \text{ V-s/A}$$

Let the radius and length of air cored solenoid be r and l, respectively such that $r << l$ and having n turns per unit length.



$$n = \frac{N}{l} \qquad ...(1)$$

where, N = total number of turns.

If i current flows through the coil, then magnetic field is given by

$$B = \mu_0 ni$$

where, n = number of turns per unit length.

Magnetic flux linked with each turn,

$$\phi = BA = \mu_0 niA$$

Total magnetic flux linked with the solenoid,

$$N\phi = (\mu_0 niA)N$$

But $N\phi = Li$

where, L is coefficient of self-induction.

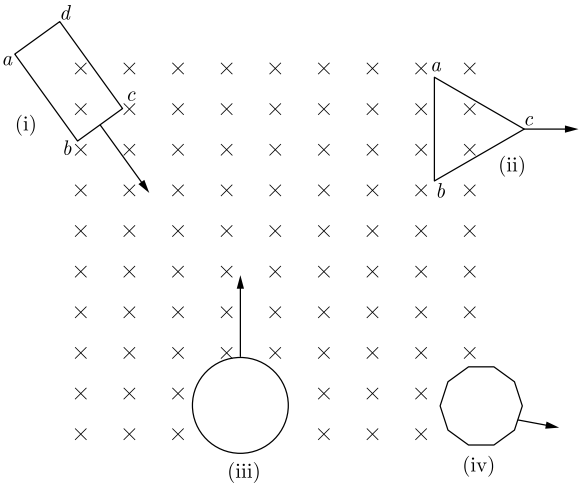
$$\mu_0 niAN = Li$$

$$L = \mu_0 nAN$$

$$= \mu_0 \left(\frac{N}{l}\right)AN = \frac{\mu_0 AN^2}{l}$$

This is the required expression.

81. Figure shows planner loops of different shapes moving out of or into a region of magnetic field which is directed normal to the plane of loops downwards. Determine the direction of induced current in each loop using Lenz's law.



Ans : **Main 2013**

(a) In fig. (i) the rectangular loop $abcd$ and in fig. (iii) circular loop are entering the magnetic field, so the flux linked with them increases. The direction of induced currents in these coils, will be such as to oppose the increase of magnetic flux, hence, the magnetic field due to current induced will be upward, i.e., currents induced will flow anti-clockwise.

(b) In fig. (ii), the triangular loop abc and in fig. (iv) the zig-zag shaped loop are emerging from the magnetic field. Therefore magnetic flux linked with these loops decreases. The currents induced in them will tend to increase the magnetic field in downward direction, so the currents will flow clockwise.

82. Find an expression of self induction of an ideal solenoid.

Ans : **Main 2025, 2010**

A long solenoid is one whose length is very large as compared to its area of cross-section. The magnetic field B at any point inside such a solenoid is practically constant and is given by

$$B = \frac{\mu_0 NI}{l} = \mu_0 nI \qquad ...(1)$$

$$\left[\text{Since, } n = \frac{N}{l}\right]$$

where, μ_0 = magnetic permeability of free space.

N = total number of turns in the solenoid,

l = length of the solenoid

n = number of turns per unit length.

Hence, Magnetic flux through each turn of the solenoid,

$$\phi = B \times \text{area of the each turn}$$

$$\phi = \left(\mu_0 \frac{N}{l} I\right)A$$

95. What is self-induction? Define self-inductance. Give its units and dimensions.

Ans : **Main 2018, 2007**

When a changing current flows through a coil, the magnetic flux linked with the coil changes and an opposing emf is induced in the coil. This emf is called self-induced emf or back emf and the phenomenon is known as self-induction.

Self-inductance or Coefficient of Self-induction

At any instant,

Magnetic flux linked with a coil $\propto$ Current through the coil.

or $$\phi \propto I$$

$$\phi = LI$$

The proportionality constant L is called self-inductance. The induced emf set up in the coil will be,

$$e = -\frac{d\phi}{dt}$$

$$= -L\frac{dI}{dt}$$

If, $$\frac{dI}{dt} = 1$$

Then, $$e = -L$$

Thus, the self-inductance of a coil may be defined as the induced emf set up in the coil due to a unit rate of change of current through it.

Units of Self-inductance

We have,

$$L = \frac{e}{dI/dt}$$

Hence, SI unit of $L = \frac{1\,\text{V}}{1\,\text{As}^{-1}}$

$$= 1\,\text{VsA}^{-1} = 1\,\text{henry (H)}$$

The self-inductance of a coil is said to be one henry if an induced emf of one volt is set up in it when the current in it changes at the rate of one ampere per second.

Also, $$L = \frac{\phi}{I}$$

So, SI unit of self-inductance is WbA^{-1}.

Hence, 1 henry, $H = 1\,\text{VsA}^{-1}$

$$= 1\,\text{WbA}^{-1}$$

Dimensions of Self-inductance

$$L = \frac{\phi}{I} = \frac{BA}{I}$$

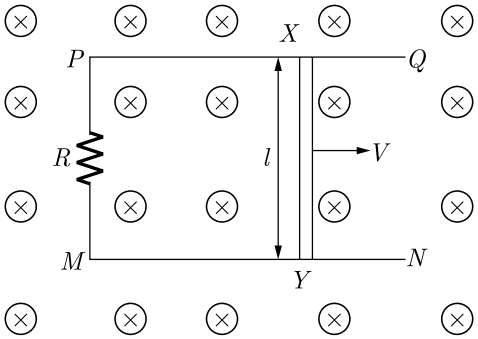
$$= \frac{F}{qv\sin\theta}\cdot\frac{A}{I}$$

Hence, Dimensions of

$$L = \frac{\text{MLT}^{-2}\cdot\text{L}^2}{\text{C}\cdot\text{LT}^{-1}\cdot\text{A}} = \frac{\text{ML}^2\text{T}^{-2}}{\text{A}\cdot\text{A}}$$

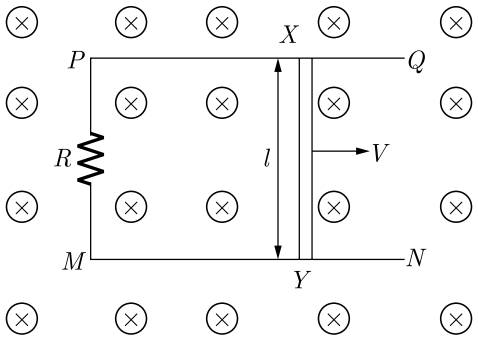
$$= [\text{ML}^2\text{T}^{-2}\text{A}^{-2}]$$

96. PQ and MN are two parallel conductors at a distance l apart and connected by a resistance R as shown in figure. They are placed in a magnetic field B which is perpendicular to the plane of the conductors. A wire XY is placed over PQ and MN and then made to slide over PQ and MN with a velocity v. Neglecting the resistance of PQ, MN and wire XY, calculate the work done per second to slide the wire XY.



Ans : **Main 2006**

When a wire slides in a magnetic field on two conducting wires, an emf is induced in the wire and current flows through the wire, hence a force acts which is opposite to the motion of the wire. According to the question, we have figure as shown below



By Faraday's law of induced emf,

$$\varepsilon = vBl$$

If resistance of loop is R, then

$$i = \frac{vBl}{R}$$

Magnetic force $= iBl\sin 90^\circ$

$$= \left(\frac{vBl}{R}\right)Bl = \frac{vB^2l^2}{R}$$

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By definition, the mutual inductance of the two solenoids is

$$M = \frac{N_2\phi_2}{i_1}$$

Putting the above value of ϕ_2, we have

$$M = \frac{\mu_0 N_1 N_2 A}{l}$$

If n_1 be the number of turns per unit length in the primary, then $n_1 = \frac{N_1}{l}$, and we have

$$M = \mu_0 n_1 N_2 A$$

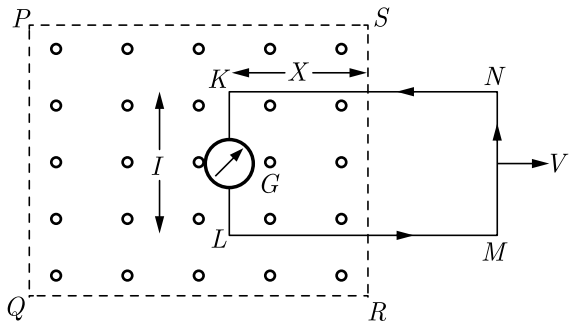
If an iron core be placed inside the primary, the magnitude of M would greatly increase.

85. Starting from the expression for the Lorentz magnetic force acting on the free charge carriers of a conductor moving in a perpendicular magnetic field, obtain the expression for the motional emf induced.

Ans : **Main 2024, 2012**

When the magnetic field is uniform and time independent and the conductor is moving in such a field, then the emf induced in the conductor is also called motional emf. In fact, the conductor has free charges and Lorentz force acting on them causes a current to be set up in the conductor. In the calculations above, $e = Blv$ is the expression for motional emf.

Induced emf by Changing the Area A : Suppose a uniform magnetic field B perpendicular to the plane of the paper and directed outwards (shown by dots in fig.) is confined in region $PQRS$. Let a rectangular loop of wire $KLMN$ be held partially in the magnetic field in the plane of the paper. Let $KL = l$. Suppose x is the portion of the loop in the field at any instant t, When the loop is moved with a velocity in the plane of the paper, area of the loop associated with the magnetic field changes. An induced emf is set up in the wire. This is detected by deflection in the galvanometer G connected in the loop.



To calculate the emf induced, suppose in a small time Δt, the loop is moved out of magnetic field through a small distance Δx.

Hence, decrease in area of the loop $= -l\Delta x$ decrease in magnetic flux linked with the loop

$$d\phi = Bl \Delta x$$

As induced emf, $e = d\phi ldt$

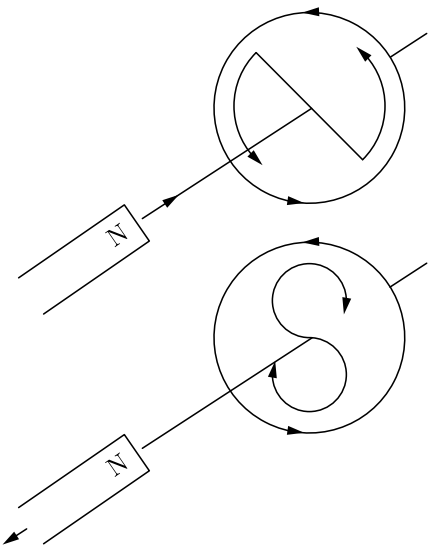
$$e = +\frac{Bl \Delta x}{\Delta t} Blv$$

i.e., $e = Blv$

86. Describe a simple experiment (or activity) to show that the polarity of emf induced in a coil is always such that it tends to produce an induced current which opposes the change of magnetic flux that produces it.

Ans : **Comp 2013, 2009**

When the North pole of a bar magnet moves towards the closed coil, the magnetic flux through the coil increases. This produces an induced emf which produces (or tend to produce if the coil is open) an induced current in the anti-clockwise sense. The anti-clockwise sense corresponds to the generation of North pole which opposes the motion of the approaching N pole of the magnet. The face of the coil, facing the approaching magnet, then has the same polarity as that of the approaching pole of the magnet. The induced current, therefore, is seen to oppose the change of magnetic flux that produces it.



When a North pole of a magnet is moved away from the coil, the current (I) flows in the clockwise sense which corresponds in the generation of South pole. The induced South pole opposes the motion of the receding North pole.

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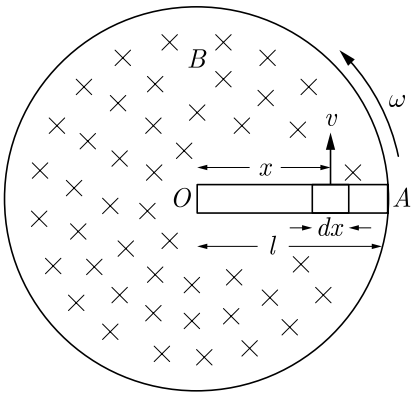
87. A conducting rod of length 'l', with one end pivoted, is rotated with a uniform angular speed 'ω' in a vertical plane, normal to a uniform magnetic field 'B'. Deduce an expression for the emf induced in this rod.

If resistance of rod is R, what is the current induced in it.

Ans : SQP 2025

Expression for Induced emf in a Rotating ROD : Consider a metallic rod OA of length l, which is rotating with angular velocity ω in a uniform magnetic field B, the plane of rotation being perpendicular to the magnetic field. A rod may be supposed to be formed of a large number of small elements.

Consider a small element of length dx at a distance x from centre. If v is the linear velocity of this element, then area swept by the element per second $= v\,dx$.



The emf induced across the ends of element,

$$de = B\frac{dA}{dt} = Bv\,dx$$

But, $v = xw$

$$de = Bx\,\omega\,dx$$

Hence, The emf induced across the rod,

$$e = \int_0^l B\,x\omega\,dx = B\omega\int_0^1 x\,dx$$

$$= B\omega\left[\frac{x^2}{2}\right]_0^l = B\omega\left[\frac{l^2}{2} - 0\right]$$

$$= \frac{1}{2}B\omega l^2$$

Current induced in rod,

$$I = \frac{e}{R} = \frac{1}{2} = \frac{B\omega l^2}{R}$$

If circuit is closed, power dissipated,

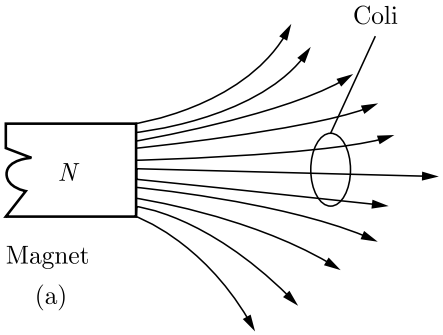
$$= \frac{e^2}{R} = \frac{B^2\omega^2 l^4}{4R}$$

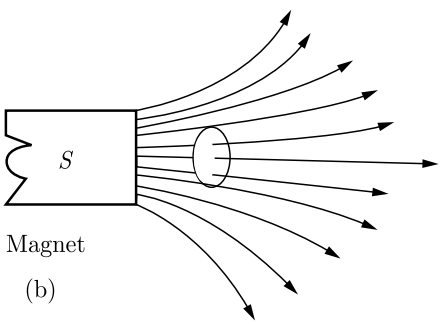
88. State Lenz's law. Give one example to illustrate the law. "The Lenz's law is a consequence of the principle of conservation of energy." Justify the statement.

Ans : Comp 2012, 2007

Lenz's law : The direction of the induced emf, or the current, in any circuit is such as to oppose the cause that produces it.

Example and Explanation : In the magnet and coil experiment, the direction of the induced current is in accordance to Lenz's law, that is, it opposes the motion of the magnet which produces it when the north pole of the magnet is moved towards the coil, the induced current flows in a direction so that the near (left) face of the coil acts as a magnetic north pole (fig. a). The repulsion between the two poles opposes the motion of the magnet towards the coil. Similarly, when the north pole of the magnet is moved away from the coil, the direction of the induced current is such as to make the near face of the coil a south pole (fig. b).The attraction between the two pole opposes the motion of the magnet away from the coil. In either case, therefore, work has to be done in moving the magnet. It is this mechanical work which appears as electrical energy in the coil.





If the direction of the induced current were such as not to oppose the motion of the magnet, then we would be obtaining electrical energy continuously without doing and work, which is impossible. Thus, Lenz's law is in accordance with the principle of conservation of energy.

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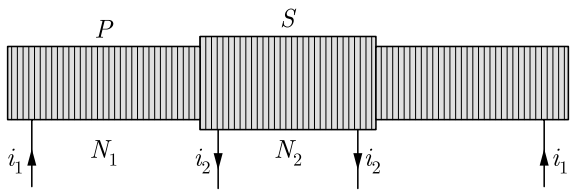
89. Deduce an expression for the mutual inductance of two long coaxial solenoids but having different radii and different number of turns.

Ans : **Main 2017**

Mutual Inductance of Two Coaxial Solenoids : Let us consider a long air-cored solenoid P (primary) of length l and area of cross-section A, having N_1 , turns (figure). Let a shorter secondary coil S having N_2 turns he would closely over the central portion of the primary P. Let, i_1 be the current in the primary. The magnitude of the magnetic field $\vec{B}$ inside the primary is, in SI unit, given by,



$$B = \mu_0 \frac{N_1}{l} i_1$$

The magnetic flux linked with the primary due to the field $\vec{B}$ is also linked with the secondary because the secondary is wound closely over the central portion of the primary. Thus, the magnetic flux linked with each turn of the secondary is,

$$\phi_2 = BA = \mu_0 \frac{N_1}{l} i_1 A$$

where, A is the area of cross-section of the secondary (although it is almost the search as of the primary).

By definition, the mutual inductance of the two solenoids is,

$$M = \frac{N_2 \phi_2}{i_1}$$

Putting the above value of ϕ_2, we have

$$M = \frac{\mu_0 N_1 N_2 A}{l}$$

If n_1 be the number of turns per unit length in the primary, then, $n_1 = \frac{N_1}{l}$, and we have

$$M = \mu_0 n_1 N_2 A$$

If an iron core be placed inside the primary, the magnitude of M would greatly increase.

90. Derive expression for self inductance of a long air-cored solenoid of length l, cross-sectional area A and having number of turns N.

Ans : **SQP 2007, 2002**

Consider a long air solenoid having n number of turns per unit length. If current in solenoid is I, then magnetic field within the solenoid,

$$B = \mu_0 nI \quad ...(1)$$

where, $\mu_0 = 4\pi \times 10^{-7}$ henry/metre is the permeability of free space.

If A is cross-sectional area of solenoid, then effective flux linked with solenoid of length 'l'; $\phi = NBA$ where $N = nl$ is the number of turns in length 'l' of solenoid.

Hence, $\phi = (nl\, BA)$

Substituting the value of B from (1)

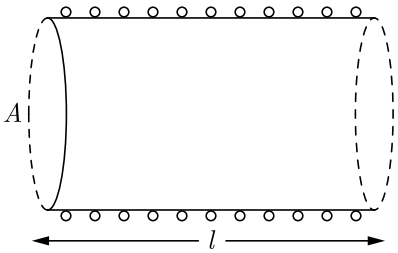
$$\phi = nl(\mu_0 nl)\, A$$

$$= \mu_0 n^2 AlI \quad ...(2)$$

Hence, self-inductance of air solenoid

$$L = \frac{\phi}{I} = \mu_0 n^2 Al \quad ...(3)$$

If N is total number of turns in length l, then



$$n = \frac{N}{l}$$

Hence, self inductance

$$L = \mu_0 \left(\frac{N}{l}\right)^2 Al = \frac{\mu_0 N^2 A}{l} \quad ...(4)$$

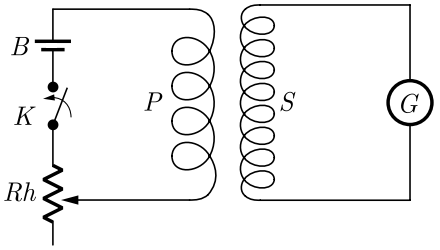
Remark- If solenoid contains a core of ferromagnetic substance of relative permeability μ_r, then self-inductance,

$$L = \frac{\mu_r \mu_0 N^2 A}{l}$$

91. What is meant by mutual induction? Define the term mutual inductance. Give its units and dimensions.

Ans : **Main 2013**

Mutual induction is the phenomenon of production of induced emf in one coil due to a change of current in the neighbouring coil.



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Period of revolution is T.

(a) Induced emf,

$$e = \frac{B\pi l^2}{T} = B\pi l^2 v$$

(b) Induced current in the rod,

$$I = \frac{e}{R} = \frac{\pi v B l^2}{R}$$

(ii) Force acting on the rod,

$$F = IlB = \frac{\pi v B^2 l^3 v}{R}$$

The external force required to rotate the rod opposes the Lorentz force acting on the rod/ external force acts in the direction opposite to the Lorentz force.

(iii) Power required to rotate the rod.

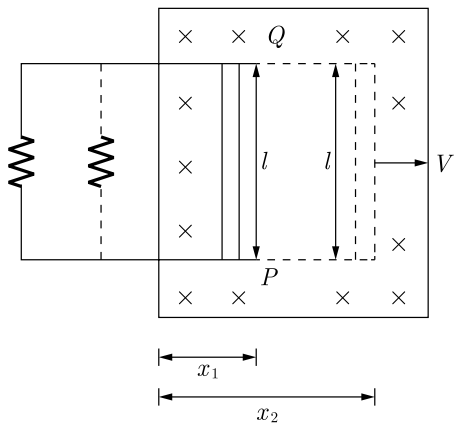
$$P = Fv = \frac{\pi v B^2 l^3 v}{R}$$

78. With the help of a neatly drawn labelled diagram, prove that the magnitude of motional emf e is given by $e = Blv$, where l is the length of a metallic rod and v is the velocity with which it is pulled in a transverse magnetic field B.

Ans : **Main 2010, 2003**

To calculate the induced emf, the rate of change of flux needs to be calculated first. Here magnetic field is uniform, so change in flux takes place due to change in area swept by loop. By calculating the rate of change of area, we can calculate the rate of change of flux, i.e. induced emf.

Let the lengths of horizontal arms of circuit be x_1 and x_2 at instants, t_1 and t_2, respectively.



Area of loop inside the magnetic field,

$$A_1 = lx_1,\ A_2 = lx_2$$

$$\Delta A = A_2 - A_1 = l(x_2 - x_1) = l\Delta x$$

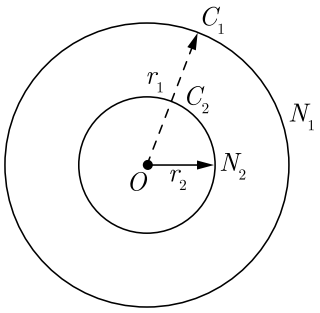
$$\Delta\phi = B\Delta A = Bl\Delta x$$

$$\frac{\Delta\phi}{\Delta t} = Bl\frac{\Delta x}{\Delta t} = Blv$$

By Faraday's law, induced emf,

$$e = \frac{\Delta\phi}{\Delta t} = vBl$$

79. Two concentric circular coils, one of small radius r_2 and the other of large radius r_1, such that $r_2 << r_1$ are placed co-axially with canters coinciding. Obtain the mutual inductance of the arrangement.



Ans : **Comp 2015**

Mutual Inductance of two plane coils : Consider two concentric circular plane coils C_1 and C_2 placed very near to each other. The number of turns in the primary coil is N_1 and radius is r_1; while the number of turns in the secondary coil is N_2 and its radius is r_2. If I_1 is the current in the primary coil, then magnetic field produced at it centre,

$$B_1 = \frac{\mu_0 N_1 I_1}{2r_1}$$

If we suppose the magnetic field to be uniform over the entire plane of secondary coil, then total effective magnetic flux linkage with secondary coil.

$$\phi_2 = N_2 B_1 A_2$$

$$= N_2\left(\frac{\mu_0 N_1 I_1}{2r_1}\right)A_2$$

$$= \frac{\mu_0 N_1 N_2 A_2}{2r_1} I_1$$

By definition, mutual inductance,

$$M = \frac{\phi_2}{I_1} = \frac{\mu_0 N_1 N_2 A_2}{2r_1}$$

But, $A_2 = \pi r_2^2$

$$M = \frac{\mu_0 N_1 N_2 \pi r_2^2}{2r_1}$$

Special case : If both coils have one turn each; then $N_1 = N_2 = 1$, so mutual inductance

$$M = \frac{\mu_0 \pi r_2^2}{2r_1}$$

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93. What is induced emf? Write Faraday's law of electromagnetic induction. Express it mathematically.

Ans : **Main 2009, 2007**

Induced EMF : The emf developed in a coil due to change in magnetic flux linked with the coil is called the induced emf.

Faraday's Law of Electromagnetic Induction : On the basis of experiments, Faraday gave two laws of electromagnetic induction.

(a) When the magnetic flux linked with a coil or circuit changes, an emf is induced in the coil. If coil is closed, the current is also induced. The emf and current last so long as the change in magnetic flux lasts. The magnitude of induced emf is proportional to the rate of change of magnetic flux linked with the circuit. Thus, if $\Delta\phi$ is the change in magnetic flux linked in time Δt, then rate of change of flux is $\frac{\Delta\phi}{\Delta t}$.

So, emf inducted,

$$e \propto \frac{\Delta \phi}{\Delta t}$$

(b) The emf induced in the coil (or circuit) opposes the cause producing it.

Hence, $$e \propto -\frac{\Delta\phi}{\Delta t}$$

Here the negative sign shown that the induced emf e opposes the change in magnetic flux

Hence, $$e = -K\frac{\Delta\phi}{\Delta t}$$

where, K is constant of proportionality which depends on units chosen for ϕ, t and e. In SI system the unit of flux ϕ is weber, unit of time t is second and unit of emf e is volt and $K = 1$,

$$e = -\frac{\Delta\phi}{\Delta t} \quad ...(1)$$

If the coil contains N-turns of insulated wire, then the flux linked with each turn will be same and the emf induced in each turn will be in the same direction. Hence the emfs of all turns will be added. Therefore, the emf induced in the whole coil,

$$e = -N\frac{\Delta\phi}{\Delta t} = -\frac{\Delta(N\phi)}{\Delta t} \quad ...(2)$$

$N\phi$ is called the effective magnetic flux or the number of flux linkages in the coil and may be denoted by ϕ.

94. Define self-inductance of a coil. Obtain the expression for the energy stored in an inductor L connected across a source of emf.

Ans : **Comp 2020**

Self Inductance

$$\phi = LI,$$

if $I = 1$ Ampere then $L = \phi$

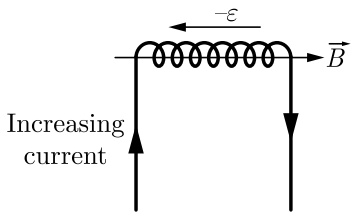
Self inductance of the coil is equal to the magnitude of the magnetic flux linked with the coil, when a unit current flows through it.

or

Using formula, $|-e| = L\frac{dI}{dt}$

If, $\frac{dI}{dt} = 1$ A/s then $L = |-e|$

Expression for magnetic energy :



When a time varying current flows through the coil, back emf $(-e)$ produces, which opposes the growth of the current flow, it means some work needs to be done against induced emf in establishing a current I. This work done will be stored as magnetic potential energy for the current I at any instant, the rate of work done is

$$\frac{dW}{dt} = (-e)I,$$

where e is self induced emf.

If we ignore the resistive losses and consider only the inductive effect, then using

$$|e| = L\frac{dI}{dt}$$

$$\frac{dW}{dt} = L\left(\frac{dI}{dt}\right)I$$

$$dW = LI\,dI$$

Hence, total amount of work done in establishing the current I,

$$W = \int dW = \int_0^I LI\,dI = \frac{1}{2}LI^2$$

Thus, the energy required to build up the current I is

$$W = \frac{1}{2}LI^2$$

This energy is stored as magnetic potential energy in the inductor.

Thus, energy, $$U = \frac{1}{2}LI^2$$

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As shown in figure, consider two coils P and S placed close to each other. If the current in the coil P is varied, the magnetic flux linked with the coil S changes which induces an emf and hence a current in it, as is seen from the deflection in the galvanometer. This coil P is called the primary coil and coil S, the secondary coil, because it is the former which causes an induced emf in the latter.

Mutual inductance or coefficient of mutual induction. At any instant,

Magnetic flux linked with the secondary coil

$$\propto \text{Current in the primary coil}$$

i.e., $\phi \propto I$

or $\phi = MI$

The proportionality constant M is called the mutual inductance or coefficient of mutual induction of the two coils. Any change in the current I sets up an induced emf in the secondary coil which is given by,

$$e = -\frac{d\phi}{dt}$$

$$= -M \cdot \frac{dI}{dt}$$

If $\frac{dI}{dt} = 1$

Then, $e = -M$

The mutual inductance of two coils may be defined as the induced emf set up in one coil when the current in the neighbouring coil changes at the unit rate.

Unit of Mutual Inductance

We have, $M = \frac{e}{dI/dt}$

Hence, SI unit of $M = \frac{1\,\text{V}}{1\,\text{As}^{-1}}$

$= 1\,\text{VsA}^{-1}$

$= 1\,\text{henry (H)}$

The mutual inductance of two coils is said to be one henry if an induced emf of one volt is set up in one coil when the current in the neighbouring coil changes at the rate of 1 ampere per second.

92. The current flowing through an inductor of self inductance L is continuously increasing. Plot a graph showing the variation of

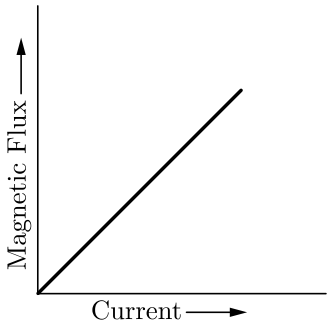
(i) Magnetic flux versus the current

(ii) Induced emf versus $\frac{dI}{dt}$

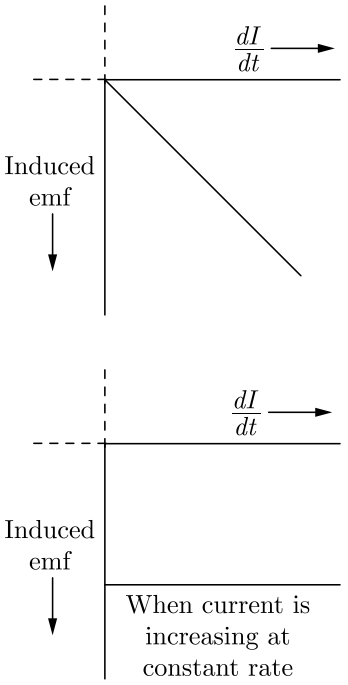
(iii) Magnetic potential energy stored versus the current.

Ans : **SQP 2017**

(i) Magnetic flux versus the current

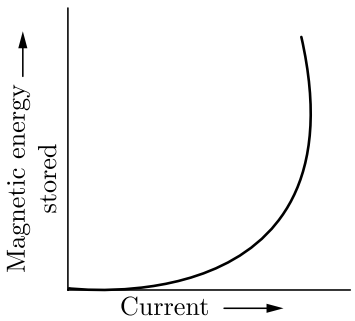


(ii) Induced emf versus $\frac{dI}{dt}$



$\frac{dI}{dt}$ is positive and e is negative and constant.

(iii) Magnetic energy stored



$$U = \frac{1}{2}LI^2 = U \propto I^2$$

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External force must be equal to magnetic force and in opposite directions.

$$\text{External force} = \frac{vB^2l^2}{R}$$

Now, if under the influence of external force, the rod XY undergoes displacement Ax in the direction of the force in time interval Δt. Then, the work done on the rod will be given by,

$$W = \text{External force} \times \Delta x$$

$$= \frac{vB^2l^2}{R} \cdot \Delta x$$

As, $$\Delta x = v \times \Delta t$$

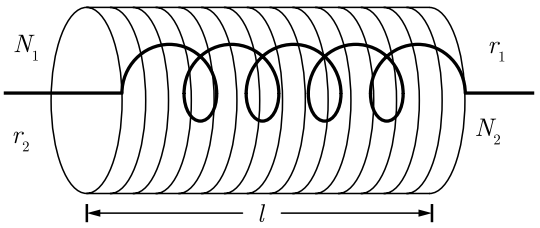
$$= \frac{v^2B^2l^2}{R}\Delta t$$

So, work done per second to slide the wire XY is $\frac{v^2B^2l^2}{R}$

97. Define mutual inductance between a pair of coils. Derive an expression for the mutual inductance of two long coaxial solenoids of same length round one over the other.

Ans : **Main 2021, 2018**

Let a current of i_1 ampere flow in the primary coil. Let, due to this current, the magnetic flux linked with each turn of the secondary coil be ϕ_2. If N_2 be the number of turns in the secondary coil, then the number of flux-linkages in the coil will be $N_2\phi_2$. This number is proportional to the current i_1 flowing in the primary coil, that is



$$N_2\phi_2 \propto i_1 \text{ or } N_2\phi_2 = Mi_1$$

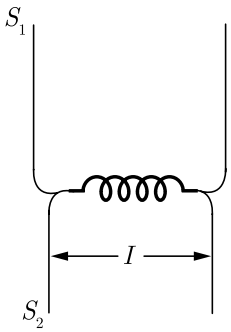
Where, M is constant, called the coefficient of mutual induction or mutual inductance of the two coils. From the equation, we have,

$$M = \frac{N_2\phi_2}{i_2}$$

If $i_2 = 1$, then $M = N_2\phi_2$

Mutual Inductance of Two Long Coaxial Solenoids

Consider two long solenoids S_1 and S_2 of same length (l), such that solenoid (S_2) surrounds solenoid (S_1) incompletely.



Let n_1, be the number of turns per unit length of S_2, n_2 be the number of turns per unit length of S_1, I_1 be current passed through solenoid S_1 and ϕ_{21} be flux linked with S_2 due to current flowing through S_1.

$$\phi_{21} \propto I_1 \text{ or } \phi_{21} = M_{21}I_1$$

Where M_{21} is the coefficient of mutual induction of the two solenoids.

When current is passed through solenoid (S_1) an emf is induced in solenoid (S_2).

Magnetic field produced inside solenoid (S_1) on passing current through it.

$$B_I = \mu_0 n_1 I_1$$

Magnetic flux linked with each turn of solenoid (S_1) will be equal to B_1 times the area of cross-section of solenoid (S_1).

Magnetic flux linked with each turn of the solenoid

$$S_1 = B_1 A.$$

Therefore, total magnetic flux linked with the solenoid (S_2),

$$\phi_{21} = B_1 A \times n_2 l$$

$$= \mu_0 n_1 I_1 \times A \times n_2 l$$

$$\phi_{21} = \mu_0 n_1 n_2 A I_2 l$$

$$M_{21} = \mu_0 n_1 n_2 A l \quad \ldots(1)$$

Similarly, the mutual inductances between the two solenoids, when current is passed through solenoid (S_2) and induced emf is produced in solenoid (S_1) and is given by

$$M_{12} = \mu_0 n_1 n_2 A l$$

$$M_{12} = M_{21} = M \quad \text{(say)}$$

Hence, coefficient of mutual induction between the two long solenoids

$$M = \mu_0 n_1 n_2 A l.$$

We can rewrite eq. (1) as

$$M = \mu_0 \left(\frac{N_1}{l}\right)\left(\frac{N_2}{l}\right)\pi r_1^2 \times l$$

$$M = \frac{\mu_1 N_1 N_2 A}{l}$$

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114. If 10 A current changes in one second through a coil and the E.M.F. induced is 10 V. What is self-inductance of the coil?

Ans : **Main 2017**

Change in current, $dI = 10\,\text{A}$

Time-taken, $dt = 1\,\text{s}$

E.M.F. induced in coil, $E = 10\,\text{Volt}$

rate of change of current,

$$\frac{dI}{dt} = \frac{10}{1} = 10\,\text{A-s}^{-1}$$

Therefore, self-inductance of the coil,

$$L = \frac{E}{\left(\frac{dI}{dt}\right)} = \frac{10}{10} = 1\,\text{H}$$

115. A toroidal solenoid with air core has an average radius of 15 cm, area of cross-section 12 cm^2 and has 1200 turns. Calculate the self-inductance of the toroid. Assume the field to be uniform across the cross- section of the toroid.

Ans : **Comp 2017**

Given, $r = 15\,\text{cm} = 0.15\,\text{m}$

$$A = 12\,\text{cm}^2 = 12 \times 10^{-4}\,\text{m}^2$$

and $N = 1200$

Self inductance,

$$L = \frac{\mu_0 N^2 A}{l} = \frac{\mu_0 N^2 A}{2\pi r}$$

$$= \frac{4\pi \times 10^{-7} \times (1200)^2 \times (12 \times 10^{-4})}{2\pi \times 0.15}$$

$$= 2.3 \times 10^{-3}\text{H}$$

116. A train is moving in N-S direction with a velocity $108\,\text{km-h}^{-1}$. If vertical component of earth's magnetic field is $8 \times 10^{-5}\,\text{T}$, What is the amount of E.M.F. generated between two wheels ? (Given: Length of axle $= 2\,\text{m}$)

Ans : **Main 2011**

Velocity of train, $v = 108\,\text{km-h}^{-1}$

$$= 30\,\text{m-s}^{-1}$$

Vertical component of earth's magnetic field,

$$B_V = 8 \times 10^{-5}\,\text{T and}$$

Length of axle, $l = 2\,\text{m}$

The amount of E.M.F. generated between two wheels of train.

$$E = B_V v l$$

$$= (8 \times 10^{-5}) \times (30) \times 2$$

$$= 4.8 \times 10^{-3}\text{V} = 4.8\,\text{mV}$$

117. There are two coils A and B separated by some distance. If a current of $2A$ flows through A, a magnetic flux of $10^{-2}\,\text{Wb}$ passes through B (no current through B). If no current passes through A and a current of 1 A passes through B, What is the flux through A?

Ans : **Main 2020**

Applying the mutual inductance of coil A with respect to coil B.

$$M_{21} = \frac{N_2 \phi_2}{I_1}$$

Therefore, we have

$$\text{Mutual inductance} = \frac{10^{-2}}{2} = 5\,\text{mH}$$

Again applying this formula for other case,

$$N_1 \phi_1 = M_{12} I_2$$

$$= 5\,mH \times 1A = 5\,\text{mWb}$$

118. The average E.M.F. induced in a coil when current changes from 0 to 3A in 0.5 s, is 15 V. What is the self-inductance of the coil?

Ans : **Main 2008**

Initial current, $I_1 = 0\,\text{A}$

Final current, $I_2 = 3\,\text{A}$

Time-taken, $dt = 0.5\,\text{s}$

Induced E.M.F., $E = 15\,\text{Volt}$

Rate of change of current,

$$\frac{dI}{dt} = \frac{I_2 - I_1}{dt}$$

$$= \frac{3-0}{0.5} = 6\,\text{A-s}^{-1}$$

Therefore, self-inductance of the coil,

$$L = \frac{E}{\left(\frac{dI}{dt}\right)} = \frac{15}{6} = 2.5\,\text{H}$$

119. When the current flowing through a coil P decreases from 5 A to 0 in 0.2 s, an emf of 60 V is induced across the terminals of an adjacent coil Q. Calculate the coefficient of mutual inductance of the two coils P and Q.

Ans : **Main 2009**

$$|\varepsilon| = \frac{d\phi}{dt} = M\frac{\Delta i}{\Delta t}$$

where, M = coefficient of mutual inductance

Δi = change in current

Δt = duration of change of current

$$M = \frac{|\varepsilon|}{\frac{\Delta i}{\Delta t}}$$

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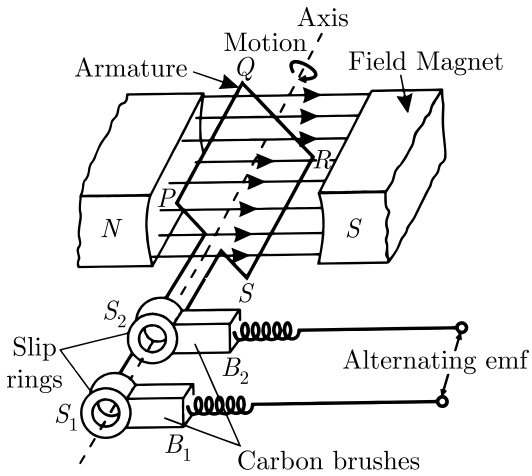


Construction :

It consists of the following main parts:

1. **Field Magnet :** N-S is either a strong permanent magnet or an electromagnet.
2. **Armature :** $PQRS$ is a rectangular armature coil. It consists of a large number of turns of insulated copper wire wound on a soft iron cylindrical core. It can be rotated about an axis perpendicular to the magnetic field of the field magnet.
3. **Slip Rings :** These are two brass rings S_1 and S_2 rigidly connected to the two ends of the armature coil. As the armature coil rotates slip rings also rotate about the same axis of rotation.
4. **Brushes :** These are two graphite rods B_1 and B_2 which remain fixed in their positions but maintain sliding contacts with the slip rings S_1 and S_2. Through these brushes, the current induced in the armature coil is fed to the external circuit.

Working : As the armature coil rotates, the magnetic flux linked with it changes and so an induced current flows through it. Initially, suppose the coil is n the vertical position and is rotated clockwise. Its side PQ moves downward and SR moves upward. By Fleming's right hand rule, the current flows from Q to P and from S to R. So during the first half rotation of the coil, the current flows in the direction $SRQP$. During the second half rotation, the direction of current is reversed, i.e., it flows along $PQRS$. The direction of current in the external circuit is reversed after every half cycle. Hence alternating current is produced by the generator.

Expression for Induced Emf :

Let, N = number of turns in the coil

A = face area of each turn

B = magnitude of the magnetic field

θ = angle which normal to the coil makes with field $\vec{B}$ at any instant t

ω = the angular velocity with which coil rotates

Then magnetic flux linked with the coil at any instant t will be,

$$\phi = NBA\cos\theta$$
$$= NBA\cos\omega t$$

Induced emf will be,

$$e = -\frac{d\phi}{dt}$$
$$= -\frac{d}{dt}(NBA\cos\omega t)$$
$$= NBA\omega\sin\omega t$$

or $$e = e_0\sin\omega t$$

where, $e_0 = NBA\omega$ = peak value of induced emf.

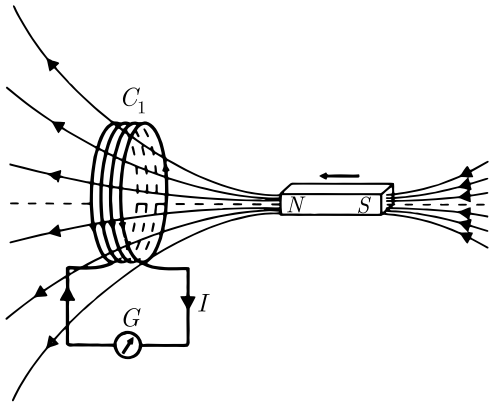
Clearly induced emf varies sinusoidally with time.

100. Describe the various experiments performed by Faraday and Henry which ultimately led to the discovery of the phenomenon of electromagnetic induction.

Ans : **Main 2019, 2015**

Faraday's Experiments :

Experiment 1 : Induced emf with a stationary coil and moving magnet.



When the Bar Magnet is Pushed Towards the Coil, the Pointer in the Galvanometer G Deflects

As shown in figure, take a coil C_1 connected to a galvanometer G. Whenever the N-pole of a bar magnet is moved towards or away from the coil, a current is induced in the coil as is shown by deflection in the galvanometer. Faster the motion of the magnet, larger is the current induced in

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Change in magnetic flux,

$$d\phi = BA\cos\theta$$
$$= 4 \times 0.5 \times \cos 60^\circ$$
$$= 4 \times 0.5 \times 0.5 = 1\,\text{Wb}$$

Therefore induced E.M.F. in the ring,

$$E = \frac{d\phi}{dt} = \frac{1}{2} = 0.5\,\text{Volt}$$

125. A rectangular coil of 300 turns has an area of 25 cm. The coil rotates with a speed of 50 c.p.s. in a uniform magnetic field of 4×10^{-2} T, about an axis perpendicular to the field. What is the value of peak induced E.M.F. in it?

Ans : **Main 2019**

Number. of turns in coil,

$$N = 300$$

Area of coil, $A = 25 \times 10 = 250\,\text{cm}^2$

$$= 250 \times 10^{-4}\,\text{m}^2$$

Angular frequency of coil,

$$f = 50\,\text{c.p.s.}$$

and angle between axis of coil and magnetic field,

$$\theta = 90^\circ$$

Angular speed of coil,

$$\omega = 2\pi f = 2\pi \times 50$$
$$= 100\pi\,\text{rad-s}^{-1}$$

Therefore value of peak induced E.M.F. in the coil,

$$E = NAB\omega\sin\theta$$
$$= 300 \times (250 \times 10^{-4}) \times (4 \times 10^{-2}) \times 100\pi \times \sin 90^\circ$$
$$= 30\pi \times 1 = 30\pi\,\text{Volt}$$

126. An AC generator generates an emf which is given by $e = 311\sin(240\pi t)\,\text{V}$. Calculate :

(a) frequency of the emf

(b) rms value of the emf

Ans : **Main 2023, 2017**

The equation for the emf generated by the AC generator is $e = 311\sin(240\pi t)\,\text{V}$.

(a) The frequency of the emf is given by the formula

$$f = \frac{\omega}{2\pi}$$

where, ω is the angular frequency, which is equal to 240π radians per second.
Therefore, the frequency is

$$f = \frac{240\pi}{2\pi} = 120\,\text{Hz}$$

So, the frequency of the emf is 120 Hz.

(b) The rms value of the emf is given by the formula.

$$E_{\text{rms}} = \frac{1}{\sqrt{2}}E_m$$

where, E_m is the maximum value of the emf, which is equal to 311 V.
Therefore, the r.m.s value is

$$E_{\text{rms}} = \frac{1}{\sqrt{2}} \times 311\,\text{V} = 220\,\text{V}$$

127. A rectangular coil of area 50 cm^2 and 100 turns is placed perpendicular to a magnetic field of $10^{-2}\,\text{Wb/m}^2$. If the coil is withdrawn from the field in 40 ms, calculate the emf induced.

Ans : **Main 2005**

When the coil is withdrawn from the magnetic field, flux linked with the coil reduced to zero. The magnetic flux through each turn of a coil of area A placed perpendicular to a magnetic field B is,

$$\phi_B = BA$$

When the coil is withdrawn from the field, the flux with it becomes zero. So, the change in flux is,

$$\Delta\phi_B = 0 - \phi_B = -\phi_B = -BA$$
$$= -(10^{-2} \times 50 \times 10^{-4})$$
$$= -5 \times 10^{-5}\,\text{Wb}$$

Time interval for the change of flux,

$$\Delta t = 40\,\text{ms} = 40 \times 10^{-3}\,\text{s}$$

By Faraday law, the emf induced in the coil is,

$$\varepsilon = -N\frac{\Delta\phi_B}{\Delta t}$$
$$= -100 \times \frac{(-5 \times 10^{-5})}{40 \times 10^{-3}}$$
$$= 0.125\,\text{V}$$

128. A transformer has 500 turns in its primary and 1000 turns in its secondary winding. The primary voltage is 200 V and the load in the secondary is $100\,\Omega$.

Calculate the current in the primary, assuming it to be an ideal transformer.

Ans : **Main 2002**

Number of turns in primary coil, $n_p = 500$

Number of turns in secondary coil, $n_s = 1000$

Resistance of secondary coil, $R_s = 100\,\Omega$

Emf of primary coil, $E_p = 200\,\text{V}$

, $\frac{E_s}{E_p} = \frac{n_s}{n_p}$

NODIA

At any instant,

Magnetic flux linked with the secondary coil

$\propto$ current in the primary coil

i.e., $\phi \propto I$

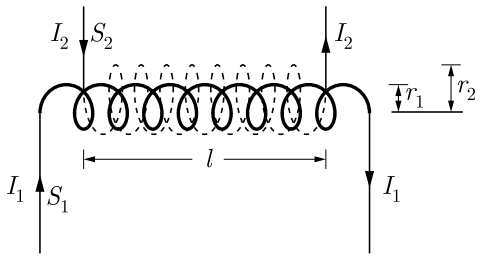
$$\phi = MI \quad ...(1)$$

The proportionality constant M is called the mutual inductance or coefficient of mutual induction of the two coil. Any change in the current I sets up an induced emf in the secondary coil which is given by,

$$\varepsilon = -\frac{d\phi}{dt} = -M \cdot \frac{dI}{dt} \quad ...(2)$$

Mutual Inductance of Two Long Solenoids

As shown in Figure consider two long co-axial solenoids S_1 and S_2, with S_2 wound over S_1.



Let, l = length of each solenoid

r_1, r_2 = radii of the two solenoids

$A = \pi r_1^2$

= area of cross-section of inner solenoid S_1

N_1, N_2 = number of turns in the two solenoids.

First we pass a time varying current I_2 through S_2.

The magnet field set up inside S_2 due to I_2 is,

$$B_2 = \mu_0 n_2 I_2$$

where, $n_2 = N_2/l$

= the number of turn per unit length of S_2.

Total magnetic flux linked with the inner solenoid S_1 is,

$$\phi_1 = B_2 A N_1 = \mu_0 n_2 I_2 . A N_1$$

Hence, Mutual inductance of coil 1 with respect to coil 2 is,

$$M_{12} = \frac{\phi_1}{I_2} = \mu_0 n_2 A N_1$$

$$= \frac{\mu_0 N_1 N_2 A}{l}$$

We now consider the flux linked with the outer solenoid S_2 due to the current I_1 in the inner solenoid S_1. The field B_1 due to I_1 is constant inside S_1 but zero in the annular region between the two solenoids.

Hence $B_1 = \mu_0 n_1 I_1$

where, $n_1 = N_1/l$

= the number of turn per unit length of S_1

Total flux linked with the outer solenoid S_2 is,

$$\phi_2 = B_1 A N_2$$

$$= \mu_0 n_1 I_1 . A N_2 = \frac{\mu_0 N_1 N_2 A l_1}{l}$$

Hence, Mutual inductance of coil 2 with respect to coil 1 is,

$$M_{21} = \frac{\phi_2}{I_1} = \frac{\mu_0 N_1 N_2 A}{l}$$

Clearly, $M_{12} = M_{12} = M$ (say)

Hence, $M = \frac{\mu_0 N_1 N_2 A}{l} = \mu_0 n_1 n_2$

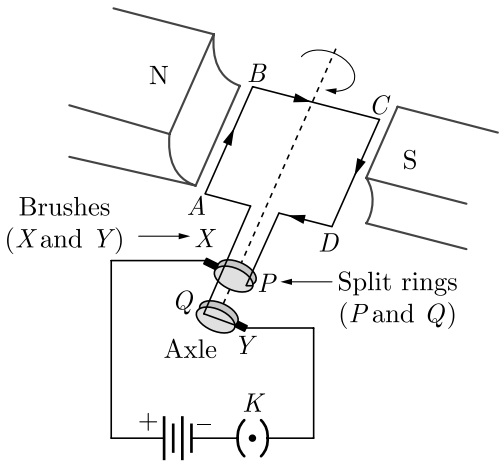
$$Al = \mu_0 n_1 n_2 \pi r_1^2 l$$

Thus, the mutual inductance of two coil is the property of their combination. It does not matter which one of them functions as the primary or the secondary coil. This fact is known as reciprocity theorem.

102. With the help of a labelled diagram describe the principle and working of an ac generator. Hence, obtain an expression for the instantaneous value of the emf generated.

Ans : **2014**

Principle : AC generator works on the principle of Faraday's law of electromagnetic induction. Whenever a coil is rotated in a uniform magnetic field about an axis perpendicular to the field, the magnetic flux linked with coil changes and an induced emf is set up across its ends.



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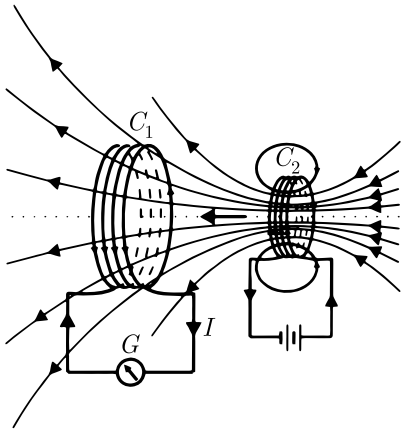
the coil. The galvanometer does not show any deflection when the magnet is held stationary.

The motion of the magnet towards or away from coil C_1 changes the magnetic flux linked with coil C_1. The change in the magnetic flux induces an emf in coil C_1 which causes a current to flow through C_1.

Experiment 2 : Induced emf due to the motion of current carrying coil.

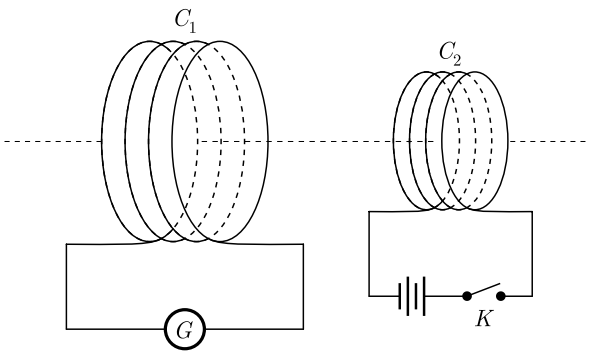


Current is Induced in Coil C_1 due to Motion of Current Carrying Coil C_2

Figure shows a coil C_1 connected to a galvanometer and coil C_2 connected to a battery. The steady current in coil C_2 produces a steady magnetic field. As the coil is moved towards C_1, the galvanometer shows a deflection. This indicates an induced current flowing through C_1. When C_2 is moved away from C_1, the direction of current through C_1 is reversed.

Due to the relative motion between coils C_1 and C_2, the magnetic flux linked with C_1 changes and an emf is induced in it.

Experiment 3 : Induced emf by changing current in the neighbouring coil.



Induced emf by Change of Current in the Neighbouring Coil

Figure shows a coil C_1 connected to a galvanometer and another coil C_2 connected to a battery through a tapping key K. When the key K is pressed, the galvanometer shows a momentary deflection. As the key is kept pressed continuously, the galvanometer shows no deflection. When the key is released, a momentary deflection is observed again, but in the opposite direction.

When the key K is pressed, the current through C_2 increases from zero to a maximum value in a short time. The flux through C_1 increases. This induces an emf in C_1. When the key is kept pressed continuously, the current through C_2 becomes constant. There is no change in flux linked with C_1 and hence induced current becomes zero. When the key is released, the current through C_2 decreases, the flux linked with C_1 decreases and hence induced current in C_1 flows in the opposite direction.

101. Define self inductance and mutual inductance. Find an expression for mutual inductance of two long coaxial solenoids.

Ans : **Main 2016, 2010**

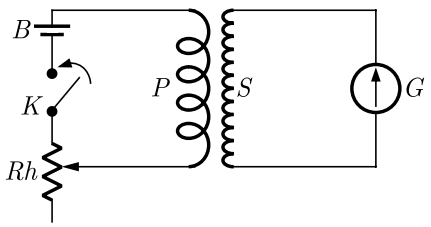
Self Inductance : When a current flows in a coil, it gives rise to a magnetic flux through the coil itself. As the strength of current changes, the linked magnetic flux changes and an opposing emf is induced in the coil. This emf is called self-induced emf or back emf and the phenomenon is known as self -induction.

$$\text{Self inductance,} \quad L = \frac{e}{dI/dt}$$

$$\text{S.I. unit of } L = \frac{1\,V}{1\,As^{-1}}$$

$$= 1\,VsA^{-1} = 1 \text{ henry } (H)$$

Mutual induction : Mutual induction is the phenomenon of production of induced emf in one coil due to a change of current in the neighbouring coil. As shown in figure consider two coil P and S placed close to each other.



The coil P is called the primary coil and coil S, the secondary coil, because it is the former which causes an induced emf in the latter.

NODIA

108. A transformer is used to step-up an alternating emf of 200 V to 440 V. If the primary coil has 1000 turns, calculate the number of turns in the secondary coil.

Ans : **Main 2014**

$$N_P = 1000,\ V_P = 200\text{ V},\ V_S = 440\text{ V}$$

We have, $\dfrac{V_S}{V_P} = \dfrac{N_S}{N_P}$

$$\frac{440}{200} = \frac{N_S}{1000}$$

$$N_S = \frac{440 \times 1000}{200}$$

$$N_S = 2200$$

109. The magnetic flux linked with a coil is given by the equation: $\phi = 3t^2 + 4t + 9$ Wb. What is the magnitude of E.M.F. induced at $t = 2$ s?

Ans : **SQP 2025**

Equation of magnetic flux,

$$\phi = 3t^2 + 4t + 9\text{ Wb}$$

Time, $t = 2\text{ s}$

E.M.F. induced in the coil,

$$E = \frac{d\phi}{dt} = \frac{d}{dt}(3t^2 + 4t + 9)$$

$$= 6t + 4$$

Therefore, E.M.F. induced in the coil at $t = 2$ s.

$$E_2 = (6 \times 2) + 4$$

$$= 16\text{ Volt}$$

110. When current flowing through one coil changes from 0 A to 15 A in 0.2 s, an emf of 750 V is induced in an adjacent coil. Calculate the coefficient of mutual inductance of the two coils.

Ans : **Main 2020**

$$|\varepsilon| = \left|\frac{d\phi}{dt}\right| = M\left|\frac{\Delta i}{\Delta t}\right|$$

$$M = -\frac{|\varepsilon|}{\left|\frac{\Delta i}{\Delta t}\right|}$$

According to the question,

$$|\varepsilon| = 750\text{ V}$$

$$\Delta i = 0 - 15 = -15\text{ A}$$

and $\Delta t = 0.2\text{ s}$

So, $M = \dfrac{750}{15/0.2} = \dfrac{750 \times 0.2}{15} = 10\text{ H}$

111. Current in a circuit falls steadily from 2.0 A to 0.0 A in 10 ms. If an average emf of 200 V in induced, then calculate the self-inductance of the circuit.

Ans : **Main 2015**

Given, $\Delta I = -2\text{ A}$

$$\Delta t = 10 \times 10^{-3}\text{ s}$$

$$V = 200\text{ Volt}$$

$$L = ?$$

Hence, Induced emf,

$$e = -L\frac{\Delta I}{\Delta t}$$

$$200 = -L\left(\frac{-2}{10 \times 10^{-3}}\right)$$

$$200 = L \times 2 \times 10^2$$

$$L = 1\text{ H}$$

112. In an ideal transformer, an output of 66 kV is required when an input voltage of 220 V is available. If the primary has 300 turns, how many turns should the secondary have?

Ans : **Main 2016, 2009**

Given

$$N_P = 300\text{ turns (turns of primary)}$$

$$V_S > V_P \text{ because } V_S = 66\text{ kV}$$

$$V_P = 220\text{ Volt}$$

Hence, $\dfrac{V_S}{V_P} = \dfrac{N_S}{N_P}$

$$\frac{66 \times 1000}{220} = \frac{N_S}{300}$$

$$N_S = \frac{66 \times 1000 \times 300}{220}$$

$$= 9 \times 10^4\text{ turns} = 90000\text{ turns}$$

113. An E.M.F. of 20 mV is induced in a coil, when the rate of change of current 4 A-s^{-1}. What is the self-inductance of the solenoid?

Ans : **Comp 2010, 2008**

Induced E.M.F., $E = 20\text{ mV}$

$$= 20 \times 10^{-3}\text{ Volt}$$

and rate of change of current,

$$\frac{dI}{dt} = 4\text{ A-s}^{-1}$$

Self-inductance of the coil,

$$L = \frac{E}{\left(\frac{dI}{dt}\right)}$$

$$= \frac{20 \times 10^{-3}}{4}$$

$$= 5 \times 10^{-3}\text{ H}$$

$$= 5\text{ mH}$$

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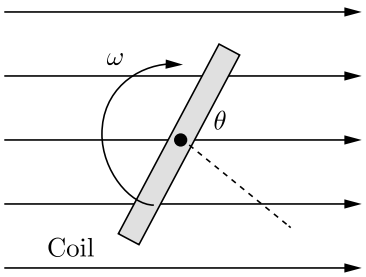
Working : When the coil starts rotating with the arm AB moving up and the arms CD moving down, cutting the magnetic lines of force, then according to Fleming's right-hand rule and the induced current is set up in these arms along the direction of AB and CD. So an effective induced current flowing in the direction of $ABCD$ is obtained. If there are large number of turns in the coil, the current generated in each turn adds upto give a large quantity of current through the coil. After half rotation of the coil, its arm CD starts moving up and AB moving down. As a result the direction of the induced currents gets reversed in the coil in the direction of $DCBA$. Thus, after every half rotation the polarity of the current in the respective arm changes. Such a current, which changes its direction after equal intervals of time, is called alternating current. To get a direct current a split ring commutator must be used in place of slip ring commutator.

Derivation : Consider a coil of N turns and area A being rotated at a constant angular velocity (ω) in a magnetic field of flux density B, its axis being perpendicular to the field. When the normal to the coil is at angle θ to the field, the flux through the coil is



$$\phi = BAN\cos\theta = BAN\cos(\omega t)$$

Since, $\theta = \omega t$

$$E = -\frac{d\phi}{dt} = \frac{-d}{dt}(BAN\cos\theta)$$

$$= BAN\,\omega\sin\omega t$$

NUMERICAL QUESTIONS

103. A coil has a self-inductance of 0.05 H. Find magnitude of the emf induced in it when the current flowing through it is changing at the rate 100 As^{-1}.

Ans : **Main 2016**

Self-inductance, $L = 0.05$ H

Rate of change of current, $\frac{di}{dt} = 100\ As^{-1}$

Magnitude of induced emf will be given as

$$e = \left|-L \times \frac{di}{dt}\right| = 0.05 \times 100$$

$$e = 5\text{ V}$$

104. A pair of adjacent coils has a mutual inductance of 1.5 H. If the current in one coil changes from 0 to 20 A in 0.5 s, what is the charge of flux linkage with the other coil ?

Ans : **SQP 2012, 2010**

Change of flux for small change in current

$$d\phi = MdI$$

$$= 1.5\,(20 - 0)$$

$$= 30\ \text{Weber}$$

105. What is the turns ratio i.e., transformer ratio, $N_s : N_p$, in an ideal transformer which increases AC voltage from 220 V to 33000 V?

Ans : **Main 2014**

Transformer ratio,

$$K = \frac{\text{Number of turns in secondary coil}\,(N_s)}{\text{Number of turns in primary coil}\,(N_p)}$$

$$\frac{N_s}{N_p} = \frac{V_s}{V_p} = \frac{33000\text{ V}}{220\text{ V}} = 150$$

where, V_s is voltage in secondary coil and V_p is voltage in primary coil.

106. A 100 mH coil carries a current of 10 A. What is the magnetic energy stored in the coil?

Ans : **SQP 2006**

Inductance of coil, $L = 100\text{ mH}$

$$= 0.1\text{ H}$$

Current, $I = 10\text{ A}$

Magnetic energy stored in the coil,

$$u = \frac{1}{2}LI^2$$

$$= \frac{1}{2} \times 0.1 \times (10)^2$$

$$= 5\text{ J}$$

107. An emf of 2 V is induced in a coil, when current in it is changed from 0 A to 10 A in 0.40 s. Find the coefficient of self-inductance of the coil.

Ans : **Main 2011**

Given, $e = 2$ V and change in current, $\frac{di}{dt} = \frac{10}{0.4}$

Coefficient of self-inductance of coil is given by

$$L = e \times \frac{dt}{di}$$

$$L = 2 \times \frac{0.4}{10} = \frac{0.8}{10} = 0.08\text{ H}$$

NODIA

Here, $|\varepsilon| = 60\text{ V}$

$\Delta I = 5 - 0 = 5\text{ A}\ \ \Delta t = 0.2\text{ s}$

So, $M = \dfrac{60}{5/0.2} = \dfrac{60 \times 2}{5 \times 10} = 2.4\text{ H}$

120. A helicopter rises vertically with a velocity of 10 m-s^{-1}. If helicopter has length of 10 m and horizontal component of earth's magnetic field is $2 \times 10^{-3}\text{ T}$. What is the E.M.F. induced between tip of nose and tail of the helicopter?

Ans : **Main 2014**

Velocity of helicopter, $v = 10\text{ m-s}^{-1}$

Length of helicopter, $l = 10\text{ m}$

and horizontal component of earth's magnetic field,

$$B_H = 2 \times 10^{-3}\text{ T}$$

E.m.f. induced between tip of nose and tail of helicopter.

$$E = B_H vl$$
$$= (2 \times 10^{-3}) \times 10 \times 10 = 0.2\text{ V}$$

121. When the current in a coil is changed from 10 A in one direction to 10 A in opposite direction in 0.5 s, an E.M.F. of 1 V is induced in it. What is the self-inductance of the coil?

Ans : **Main 2018**

Initial current, $I_1 = 10\text{ A}$

Final current, $I_2 = -10\text{ A}$

(Negative sign due to opposite direction);

Time-taken, $dt = 0.5\text{ s}$

Induced E.M.F. in coil,

$$E = 1\text{ Volt}$$

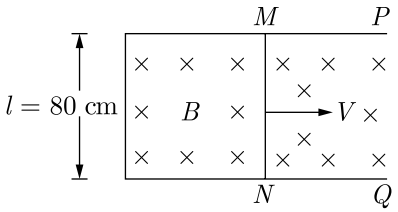
Rate of change of current,

$$\frac{dI}{dt} = \frac{I_1 - I_2}{dt}$$
$$= \frac{10 - (-10)}{0.5} = 40\text{ A-s}^{-1}$$

Therefore, self-inductance of the coil,

$$L = \frac{E}{\left(\frac{dI}{dt}\right)}$$
$$= \frac{1}{40} = 0.025\text{ H} = 25\text{ mH}$$

122. Figure below shows a metallic rod MN of length l = 80 cm, kept in a uniform magnetic field of flux density B = 0.5 T, on two parallel metallic rails P and Q. Calculate the emf that will be induced between its two ends, when it is moved towards right with a constant velocity v of 36 km/h.



Ans : **Main 2020**

The motional emf associated with a moving rod in a magnetic field is $\varepsilon = vBl$

Length of the rod,

$$l = 80\text{ cm} = 0.8\text{ m}$$

Velocity, $v = 36\text{ km/h} = 10\text{ m/s}$

and magnetic field, $B = 0.5\text{ T}$

$$\varepsilon = 10 \times 0.5 \times 0.8 = 4\text{ V}$$

123. In a closed circuit of resistance $10\,\Omega$, the linked flux varies with time according to relation $\phi = 6t^2 - 5t + 1$. At $t = 0.25$ second, What is the current (in Ampere) flowing through the circuit?

Ans : **Main 2016**

Given, $\phi = 6t^2 - 5t + 1$

We know that, $e = \dfrac{-d\phi}{dt}$

$$= \frac{-d(6t^2 - 5t + 1)}{dt}$$
$$= -12t + 5$$

Here, $t = 0.25$

$$= -12 \times 0.25 + 5$$
$$= -3 + 5 = 2\text{ Volt}$$

Now, Current, $I = \dfrac{e}{R}$

Here, $R = 10\,\Omega$

$$= \frac{2}{10} = 0.2\text{ A}$$

124. A circular ring of area of 0.5 m^2 is situated in a non-uniform magnetic field of 4T changing in $2\,s$ and making an angle of 60° with the magnetic field. What is the magnitude of the induced E.M.F.?

Ans : **Comp 2019, 2007**

Area of ring, $A = 0.5\text{ m}^2$

Magnetic field, $B = 4\text{ T}$

and angle which the ring makes with the magnetic field,

$$\theta = 60^\circ$$

NODIA

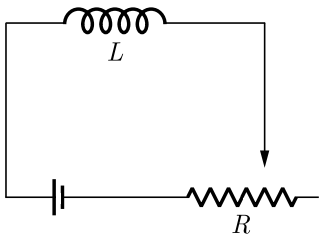
98. Define the term self-inductances of a solenoid. Obtain the expression for the magnetic energy stored in an inductor of self-inductance L to build up a current I through it.

Ans : **Main 2013, 2009**

(i) **Self-inductance :** Self-inductance is the property of a coil by virtue of which, the coil opposes any change in the strength of current flowing through it by inducing an emf in itself.

The induced emf is also called back emf. When the current in a coil is switched on, the self-induction opposes the growth of the current and when the current is switched off, the self-induction opposes the decay of the current,

So, self-induction is also called the inertia of electricity



(ii) **Self-inductance of long solenoid :** A long solenoid is one whose length is very large as compared to its area of cross-section.

The magnetic field (B) at any point inside such a solenoid is practically constant and is given by

$$B = \frac{\mu_0 NI}{I} \qquad ...(1)$$

Where, μ_0 = absolute magnetic permeability of free space,

N = total number of turns in the solenoid.

and I = length of the solenoid

Hence, Magnetic flux through each turn of the solenoid,

ϕ = $B \times$ area of the each turn

$$\phi = \left(\mu_0 \frac{N}{I} I\right) A$$

where, A = area of each turn of the solenoid.

Total magnetic flux linked with the solenoid.

= flux through each turn $\times$ total number of turns

$$N\phi = \mu_0 \frac{N}{I} IA \times N \qquad ...(2)$$

If L is coefficient of self-inductance of the solenoid, then

$$N\phi = LI \qquad ...(3)$$

From eqs. (2) and (3), we get

$$LI = \mu_0 \frac{N}{I} IA \times N$$

or $$L = \frac{\mu_0 N^2 A}{I}$$

If core is of any other magnetic material μ is placed, then

$$\mu = \mu_0 \ \mu_r$$

$$L = \frac{\mu_0 \mu_r N^2 A}{I}$$

The magnitude of emf is given by

$$e = L\frac{dI}{dt}$$

Multiplying (I) to both sides, we get

$$eI\,dt = LI\,dI \qquad ...(4)$$

But, $$I = \frac{dq}{dt} \text{ or } Idt = dq$$

Also, work done (dW)

= voltage (e) $\times$ charge (dq)

or $$dW = e \times dq = eIdt \qquad ...(5)$$

Subtracting eq. (5) in eq. (4), we get,

$$dW = LIdI \qquad ...(6)$$

Total work done in increasing the current from zero to I_0, by integrating both sides of eq. (5) we get,

$$\int_0^W dW = \int_1^{I_0} LIdI$$

$$W = \frac{1}{2} LI_0^2$$

This work done in increasing the current flowing through the inductor is stored in the potential energy (U) in the magnetic field of inductor.

$$U = \frac{1}{2} LI_0^2 C$$

99. With the help of a labelled diagram, explain the principle, construction and working of an ac generator. Derive the expression for induced emf.

Ans : **Comp 2024, 2018**

It is a device which converts mechanical energy into alternating form of electrical energy.

Principle : The working of an AC generator is based on the principle of electromagnetic induction. When a closed coil is rotated in a uniform magnetic field with its axis perpendicular to the magnetic field, the magnetic flux linked with the coil changes and an induced emf and hence a current is set up in it.

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$$\frac{E_s}{200} = \frac{1000}{500}$$

$$E_s = 400\ \text{V}$$

Current in secondary coil,

$$i_s = \frac{E_s}{R_s} = \frac{400}{100} = 4\ \text{A}$$

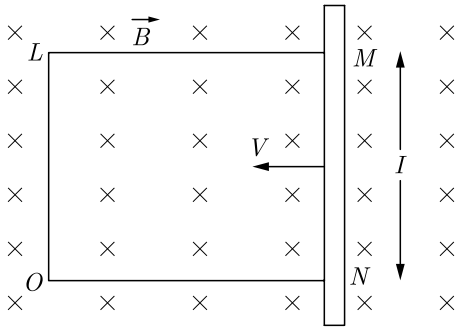
For an ideal transformer,

$$E_p i_p = E_s i_s$$

Current in primary coil,

$$i_p = \frac{E_s i_s}{E_p} = \frac{400 \times 4}{200} = 8\ \text{A}$$

129. A rectangular conductor $LMNO$ is placed in a uniform magnetic field of 0.5 T. The field is directed perpendicular to the plane of the conductor. When the arm MN of length of 20 cm is moved towards left with a velocity of 10 ms^{-1} , calculate the emf induced in the arm. Given the resistance of the arm to be $5\,\Omega$ (assuming that other arms are of negligible resistance) find the value of the current in the arm.



Ans : **Main 2021**

Induced arm in a moving rod in a magnetic field is given by

$$\varepsilon = -Blv$$

Since the rod is moving to the left so

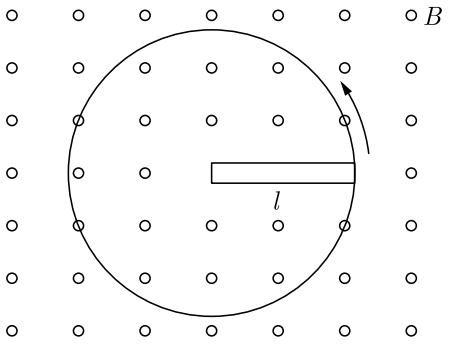
$$\varepsilon = +Blv$$

$$= 0.5 \times 0.2 \times 10 = 1v$$

Current in the rod $I = \frac{\varepsilon}{R} = \frac{1}{5} = 0.2$ A

130. A horizontal conducting rod 10 m long extending from east to west is falling with a speed 5.0 ms^{-1} at right angle to the horizontal component of the Earth's magnetic field, 0.3×10^{-4} $\text{Wb} - \text{m}^{-2}$. Find the instantaneous value of the emf induced in the rod.

Ans : **Comp 2020, 2014**



Given, $B = 0.3 \times 10^{-4}\ \text{Wb-m}^{-2}$

$v = 5\ \text{m/s}$

$\theta = 90^\circ$

$l = 10\ \text{m}$

$e = B\,vl \sin\theta$

$= 0.3 \times 10^{-4} \times 10 \times 5 \times \sin 90^\circ$

$= 15 \times 10^{-4}\text{V}$

Hence, $e = 1.5 \times 10^{-3}\text{V}$

$= 1.5\ \text{mV}$

131. A wheel with 8 metallic spokes each 20 cm long is rotated with a speed of 120 rev/min in a plane normal to the horizontal component of the Earth's magnetic field. The Earth's magnetic field at the plane is 0.4 G and the angle of dip is 60°. Calculate the emf induced between the axle and the rim of the wheel. How will the value of emf be affected if the number of spokes were increased?

Ans : **Main 2021**

If a rod of length l rotates with angular speed ω in uniform magnetic field B

$$e = \frac{1}{2}Bl^2\omega$$

In case of Earth's magnetic field

$$B_H = |B_e| \cos\theta$$

and $B_v = |B_e| \sin\theta$

$$e = \frac{1}{2}|B_e| \cos\theta l^2\omega$$

$$= \frac{1}{2} \times 0.4 \times 10^{-10} \times \cos 60^\circ \times (0.5)^2 \times 2\pi v$$

$$= \frac{1}{2} \times 0.4 \times 10^{-4} \times \frac{1}{2} \times (0.5)^2 \times 2\pi \times \left(\frac{120}{60}\right)$$

$$= 10^{-5} \times 0.2.5 \times 2 \times 3.14 \times 2$$

$$= 3.14 \times 10^{-5}\ \text{Volt.}$$

Induced emf is independent of the number of spokes i.e., it will remain same.

NODIA

According to Lenz's law, the direction of induced current is from D to C or anti-clockwise.

137. The primary coil of a transformer has 60 turns, whereas its secondary coil has 3000 turns.

(a) If a 220 V AC voltage is applied to the primary coil. How much emf is induced in the secondary coil?

(b) If a current of 5 A flows in the primary coil. How much current will flow in a load in the secondary coil? State the assumption you have made regarding the transformer, in this calculation.

Ans : **Main 2016**

The primary coil of a transformer has 60 turns and the secondary coil has 3000 turns.

(a) The transformer equation is

$$\frac{V_P}{V_S} = \frac{N_P}{N_S}$$

where, V_P and V_S are the voltage in the primary and secondary coils respectively, and N_P and N_S are the number of turns in the primary and secondary coils, respectively.

If a 220 V AC voltage is applied to the primary coil, then the voltage induced in the secondary coil is,

$$\frac{V_P}{V_S} = \frac{N_P}{N_S}$$

$$\frac{220}{V_S} = \frac{60}{3000}$$

$$V_S = \frac{3000 \times 220}{60}$$

$$V_S = 110000 \text{ Volt}$$

Therefore, the emf induced in the secondary coil is 110 kV.

(b) According to the transformer equation, the current in the secondary coil is

$$\frac{I_P}{I_S} = \frac{N_S}{N_P}$$

where, I_P and I_S are the current in the primary and secondary coils, respectively and N_P and N_S are the number of turns in the primary and secondary coil, respectively.

Assuming an ideal transformer, which means that there is no energy loss in the transformer, we can say that the power in the primary coil is equal to the power in the secondary coil. Thus, we use the formula

$$I_p V_p = I_s V_s$$

where, I_P and V_P are the current and voltage in the primary coil and I_S and V_S are the current and voltage in the secondary coil. Substituting the values, we get

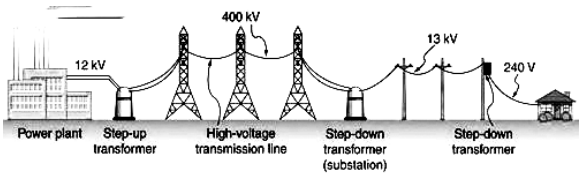
$$5 \text{ A} \times 220 \text{ V} = I_S \times 110000 \text{ V}$$

$$I_S = 1 \times 10^{-2} \text{ A}$$

Therefore, the current flowing in the load in the secondary coil is 1×10^{-2} A.

CASE BASED QUESTIONS

138. A small town with a demand of 800 KW of electric power at 220 V is situated 15 km away from an electric plant generating power at 440 V. The resistance of the two wire line carrying power is $0.5\,\Omega$ per km. The town gets power from the line through a 4000-220 V step-down transformer at a sub-station in the town.



(a) Estimate the line power loss in the form of heat.

(b) How much power must the plant supply, assuming there is negligible power loss due to leakage?

(c) Characterise the step up transformer at the plant.

Ans :

$$\text{Line resistance} = 30 \times 0.5$$

$$= 15\,\Omega$$

Rms current in the line

$$800 \times 1000 \text{ W}/4000 \text{ V} = 200 \text{ A}$$

(a) Line power loss

$$= (200)^2 \times 15$$

$$= 600 \text{ KW}.$$

(b) Power supply by the plant

$$800 \text{ KW} + 600 \text{ KW} = 1400 \text{ KW}$$

(c) Voltage drop on the line $= 200 \times 15$

$$= 3000 \text{ Volt}$$

The step-up transformer at the plant is 440 Volt-7000 Volt.

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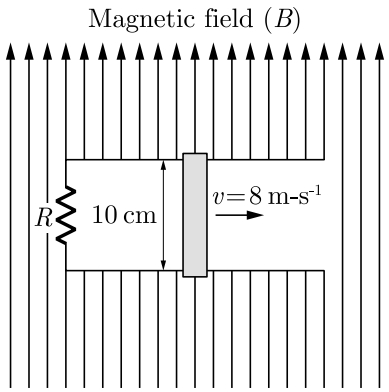
$$= -3 \times 10^{-2} \times 1 \times 2$$

$$= -6 \times 10^{-2}\ \text{V}$$

Current, $I = \dfrac{e}{R}$

$$= \frac{6 \times 10^{-2}}{6} = 10^{-2} = 0.01\ \text{A}$$

135. A metal rod makes contact and completes the circuit as shown in the figure. The direction of motion of rod is perpendicular to the magnetic field of 0.5 T. If the resistance R is 2Ω, what is the force needed to move the rod as indicated with a constant velocity of $8\ \text{m-s}^{-1}$?



Ans : SQP 2013

Magnetic field, $B = 0.5\,T$

Resistance, $R = 2\Omega$

Velocity of rod, $v = 8\ \text{m-s}^{-1}$

Length of rod, $l = 10 = 0.1\ \text{m}$

E.M.F. induced in the rod,

$$E = Bvl$$

$$= 0.5 \times 8 \times 0.1$$

$$= 0.4\ \text{Volt}$$

Therefore, induced current in the rod,

$$I = \frac{E}{R} = \frac{0.4}{2} = 0.2\ \text{A}$$

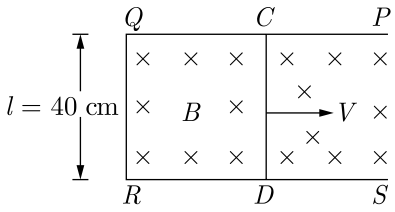
We also know that force acting on the rod in magnetic field,

$$F = BIl$$

$$= 0.5 \times 0.2 \times 0.1$$

$$= 0.01\ \text{N}$$

136. A metallic rod CD rests on a thick metallic wire $PQRS$ with arms PQ and RS parallel to each other, at a distance $l = 40$ cm, as shown in figure.



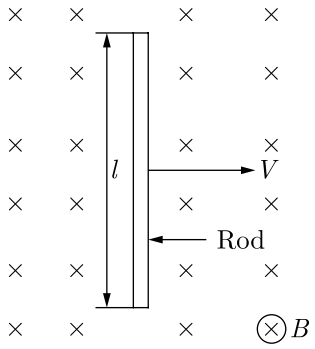
A uniform magnetic field $B = 0.1$ T acts perpendicular to the plane of this paper, pointing inwards (i.e. away from the reader). The rod is now made to slide towards right with a constant velocity of $v = 5.0\ \text{ms}^{-1}$.

(i) How much emf is induced between the two ends of the rod CD ?

(ii) What is the direction in which the induced current flows?

Ans : Main 2013, 2010

(i) Motional emf associated with a moving rod in a magnetic field is



$$\varepsilon = vBl$$

where, ε = emf induced

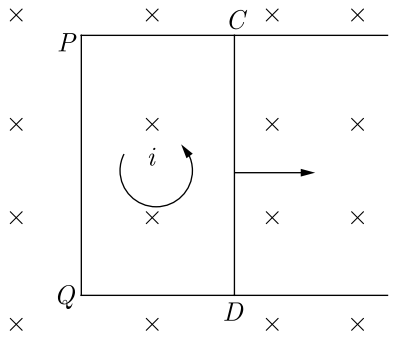
v = speed of the rod

l = length of the rod

Given, $v = 5\ \text{m/s},\ l = 40\ \text{cm},\ B = 0.1\ \text{T}$

$$\varepsilon = vBl = 5 \times 0.1 \times 0.4 = 0.2\ \text{V}$$

(ii)



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132. A horizontal electric pole wire 200 m long is lying along the earth's magnetic field at a height of 10 m. If horizontal component of the earth's magnetic field in 0.32×10^{-4} T, what is E.M.F. induced in the wire, on striking the ground?

Ans : **Main 2024**

Length of wire, $l = 200\,\text{m}$

Height of wire from the ground,

$$h = 10\,\text{m}$$

Initial speed of wire,

$$u = 0 \qquad \text{(because is at rest)}$$

and horizontal component of earth's magnetic field,

$$B_H = 0.32 \times 10^{-4}\,\text{T}$$

relation for the final speed of wire on striking the ground v is,

$$v^2 = u^2 + 2gh$$
$$= (0)^2 + 2 \times 9.8 \times 10$$
$$= 196$$
$$v = \sqrt{196} = 14\,\text{m-s}^{-1}$$

Since, horizontal component of the earth's magnetic field is normal to wire and direction of motion of wire, therefore E.M.F. induced in the wire on striking the ground.

$$E = B_H vl$$
$$= (0.32 \times 10^{-4}) \times 14 \times 200$$
$$= 0.09\,\text{Volt}$$

133. The current flowing in the two coils of self-inductance $L_1 = 16\,\text{mH}$ and $L_2 = 12\,\text{mH}$ are increasing at the same rate. If the power supplied to the two coils are equal, find the ratio of

1. Induced voltages
2. The current and
3. The energies stored in the coil at a given instant.

Ans : **Main 2018, 2015**

Given, $L_1 = 16\,\text{mH}$

$L_2 = 12\,\text{mH}$

1. Induced voltage is given by,

$$v = L\frac{dI}{dt}$$
$$v \propto L$$
$$\frac{v_1}{v_2} = \frac{L_1}{L_2} \qquad \left(\text{as } \frac{dI}{dt} \text{ is same}\right)$$
$$\frac{v_1}{v_2} = \frac{16}{12} = \frac{4}{3} \qquad \ldots(1)$$

2. The current is given by,

$$\text{Power, } P = Iv$$

Now, $\frac{I_1}{I_2} = \frac{v_2}{v_1}$ (as P is the same)

$$\frac{I_1}{I_2} = \frac{3}{4} \qquad \ldots(2)$$

3. Energy stored is given by, coil 1 and coil 2.

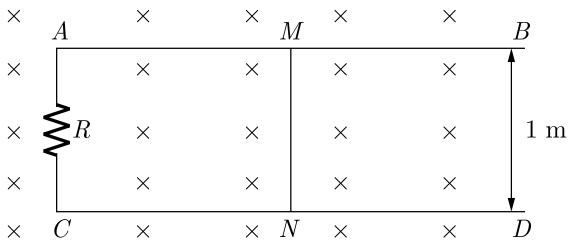
$$E_1 = \frac{1}{2}L_1 I_1^2 \qquad \ldots(3)$$

$$E_2 = \frac{1}{2}L_2 I_2^2 \qquad \ldots(4)$$

On dividing equation (3) and (4), we get

$$\frac{E_1}{E} = \frac{L_1 I_1^2}{L_2 I_2^2}$$
$$= \frac{16}{12} \times \frac{9}{16} \qquad \text{[From Eq. (2)]}$$
$$\frac{E_1}{E_2} = \frac{3}{4}$$

134. AB and CD are two parallel conductors kept 1 m apart and connected by a resistance R of $6\,\Omega$, as shown in figure below. They are placed in a magnetic field $B = 3 \times 10^{-2}\,\text{T}$ which is perpendicular to the plane of the conductors and directed into the paper. A wire MN is placed over AB and CD and then made to slide with a velocity 2 ms^{-1}. (Neglect the resistance of AB, CD and MN.)



Calculate the induced current flowing through the resistor R.

Ans : **Main 2017**

$$B = 3 \times 10^{-2}\,\text{T}$$
$$MN = BD = 1\,\text{m}$$
$$v = 2\,\text{ms}^{-1}$$

The emf induced in the coil,

$$e = -\frac{d\phi}{dt}$$
$$e = -\frac{d(BA)}{dt}$$

$A =$ area of the loop $= l \times x$

$$e = -\frac{d(Bl \times x)}{dt} = -Bl\frac{dx}{dt} = -Blv$$

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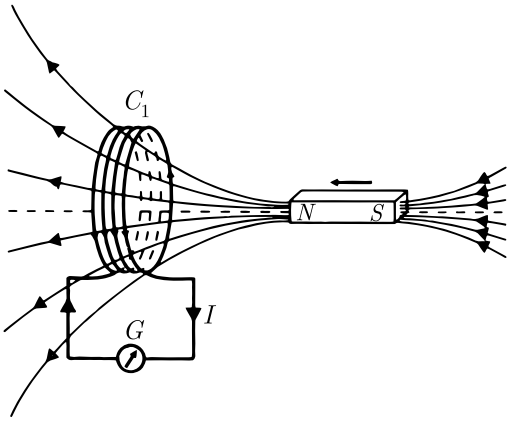
139. Faraday's second law of EMI says that magnitude of emf induced in a circuit is directly proportional to the rate of change of magnetic flux linked with the circuit, i.e., $\varepsilon \propto \frac{d\phi}{dt}$. It means if the magnetic flux linked with a circuit charges at a faster rate, the induced emf is larger and vice-versa.



Read the above passage and answer the following question.

(i) Coil A is held in a very strong magnetic field and coil B is held in a weak magnetic field. In which cell do you expect larger induced emf?

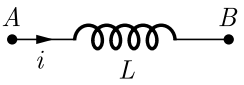
(ii) A coil is moved in a uniform magnetic field. When do you expect induced emf in the coil?

Ans :

(i) Induced emf in both the coils is zero. This is because magnetic flux linked with A or B larger and magnetic flux linked with B is smaller, but amount of magnetic flux linked with the coil does not induce emf in the coil. The magnetic flux must change to induce emf.

(ii) Induced emf would develop in the coil, when it is entering the magnetic field or leaving the magnetic field, i.e., when the coil is partially in magnetic field and partially out of magnetic field. This is because magnetic flux linked with the coil would change only in these situations. When the entire coil is moving in the magnetic field, magnetic flux linked with the coil is consistent, but it is not changing. Therefore, there is no induced emf in the coil.

140. An inductor is simply a coil or a solenoid that has a fixed inductance. It is referred to as a choke. The usual circuit rotation for an inductor is as shown.



Let a current i flows through the inductor from A to B. Whenever, electric current changes through it, a back emf is generated. If the resistance of inductor is assumed to be zero (ideal inductor) then induced emf in it is given by

$$e = V_B - V_A = -Ldi/dt$$

Thus, potential drops across an inductor as we moves the direction of current. But potential also drops across a pure resistor when we move in the direction of the current. The main difference between a resistor and an inductor is that while a resistor opposes the current through it, an inductor opposes the change in current through it.

Now answer the following questions.

(1) How does inductor behave when a steady current flow through it?

(2) How does inductor behave when a steadily increasing current flows through it?

(3) How does inductor behave when a steadily decreasing current flows through it?

(4) Name the phenomenon in which change in current in a coil induces EMF in a coil itself?

Ans :

(1) As electric current is steady therefore

$$di/dt = 0;$$

induced emf $= e$

$= 0$ and the inductor behaves as short circuit.

(2) In the expression

$$e = -Ldi/dt$$

as $\frac{di}{dt}$ is positive EMF is negative, that is $V_B < V_A$

That is back EMF is generated that opposes the increase in current.

(3) $\frac{di}{dt}$ is negative, therefore EMF is positive, that is $V_B > V_A$ Forward EMF is generated that opposes fall in current.

(4) Self induction.

141. Faraday established that an emf can be induced in a coil by changing the amount of magnetic flux (ϕ) linked with the coil. As $\phi = BA\cos\theta$, therefore three methods of inducing emf are by changing magnetic field E or by changing area A or by changing relative orientation θ of the coil w.r.t. the magnetic field.

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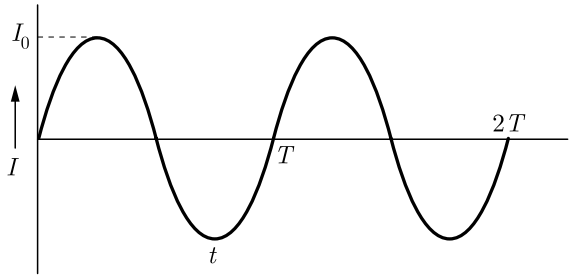
CHAPTER 7

Alternating Current

SUMMARYS

1. ALTERNATING CURRENT (AC)

It is the current which varies in both magnitude as well as direction alternatively and periodically as shown in the figure.



$$I = I_0 \sin \omega t \text{ or } I = I_0 \cos \omega t$$

where, $I_0 =$ peak value of AC

2. MEAN AND RMS VALUE OF ALTERNATING CURRENT

An electrical device reads root mean square value as,

$$I_{rms} = \frac{I_0}{\sqrt{2}} = 0.707 I_0$$

Then mean value of alternating current over complete cycle is zero.

$$(I_{\text{mean}})_{\text{full cycle}} = 0$$

While for cycle it is,

$$(I_{\text{mean}})_{\text{half cycle}} = \frac{2I_0}{\pi} = 0.636 I_0$$

3. ALTERNATING EMF OR VOLTAGE

It is the emf which varies in both magnitude as well as direction alternatively and periodically. The instantaneous alternating emf is given by

$$V = V_0 \sin \omega t$$

$$V = V_0 \cos \omega t$$

$$V_{\text{rms}} = \frac{V_0}{\sqrt{2}} = 0.707$$

$$V_{rms} = 7.07\% \text{ of } V_0$$

$$V_{av} = \frac{2V_0}{\pi} = 0.637$$

$$V_{av} = 6.37\% \text{ of } V_0$$

4. REACTANCE

The opposition offered by inductance and capacitance or both in AC circuit is called reactance. It is denoted by X_C or X_L. The opposition due to inductor alone is called the inductive reactance while that due to capacitance alone is called the capacitive reactance.

Inductive reactance,

$$X_L = \omega L = 2\pi f L \qquad (\therefore \omega = 2\pi f)$$

Capacitive reactance,

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$$

5. POWER

In an AC circuit, both emf and current change continuously w.r.t. time, so in circuit we have to calculate average power in complete cycle $(O_{(\text{zero})} \rightarrow T)$

$$P = V_{rms} I_{rms} \cos \phi$$

Where, $\cos \phi =$ power factor

5.1 Purely Resistive Circuit

If a circuit contains pure resistance, then difference $\phi = 0$ i.e., current and voltage are in the same phase impedance.

5.2 Purely Inductive Circuit

If a circuit contains pure inductance, then $\phi = \frac{\pi}{2}$, i.e., current lags behind the applied voltage by an angle $\frac{\pi}{2}$.

If, $V = V_0 \sin \omega t$

Then, $I = I_0 \sin\left(\omega t - \frac{\pi}{2}\right)$

In this case inductive reactance, $X_L = \omega L$.

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(e) Power expended by an external agent against the above retarding force to keep the rod moving uniformly at 12 cm

$$= 75 \times 10^{-3} \times 12 \times 10^{-2}$$

$$= 9.0 \times 10^{-3} \text{ W}$$

When K is open, no power is expended.

(f) $$I^2R = 1 \times 1 \times 9 \times 10^{-3}$$

$$= 9.0 \times 10^{-3} \text{ W}$$

The source of this power is the power provided by the external agent as calculated above.

(g) Zero motion of the rod does not cut across the field lines

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Then,

1. Impedance,

$$Z = \frac{V_{rms}}{I_{rms}} = \sqrt{R^2 + X_C^2}$$

2. For the phase angle,

$$\tan\phi = \frac{X_C}{R} = \frac{1}{\omega CR}$$

3. If $V = V_0 \sin\omega t$, then

$$I = I_0 \sin(\omega t + \phi)$$

4. Power factor,

$$\cos\phi = \frac{R}{Z} = \frac{R}{\sqrt{R^2 + X_C^2}}$$

5.6 In an L-C Series AC Circuit

1. Impedance,

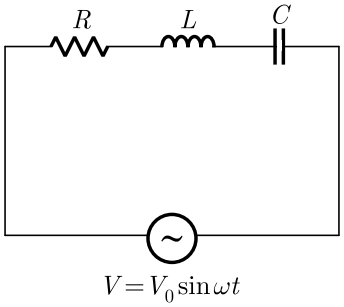
$$Z = \frac{V_{rms}}{I_{rms}} = X_L - X_C$$

2. Phase difference between voltage and current is $\frac{\pi}{2}$.

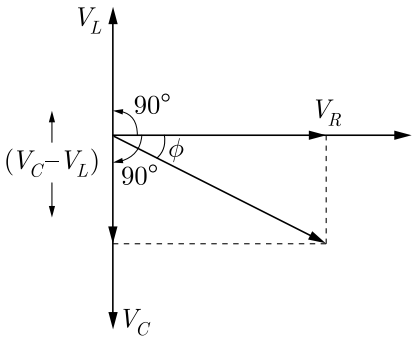
3. Power factor, $\cos\phi = 0$.

5.7 In L-C-R Circuit

The LCR Circuit diagram is shown below :



(a)



(b)

If a circuit contains inductance L, capacitance C and resistance R, connected in series to an alternating voltage,

$$V = V_0 \sin\omega t$$

Then impedance, $Z = \sqrt{R^2 + (X_C - X_L)^2}$

and phase, $\phi = \tan^{-1}\frac{X_C - X_L}{R}$

Net Voltage, $V = \sqrt{V_R^2 + (V_C - V_L)^2}$

5.8 Resonant Circuits

In series LCR circuit, when phase ϕ between current and voltage is zero, the circuit is said to be resonant circuit.

In resonant circuit,

$$X_C = X_L$$

or $$\frac{1}{\omega C} = \omega L$$

$$\omega = \frac{1}{\sqrt{LC}}$$

Resonant angular frequency,

$$\omega_r = \frac{1}{\sqrt{LC}}$$

Linear frequency, $f_r = \frac{\omega_r}{2\pi}$

$$= \frac{1}{2\pi\sqrt{LC}}$$

At resonant frequency,

$$\phi = 0, V = V_R.$$

6. AC GENERATOR

It is a device used to convert mechanical energy into electrical energy and is based on the phenomenon of electromagnetic induction. If a coil of N turns, area A is rotated at frequency f in uniform magnetic field of induction B, then motional emf in coil (if initially it is perpendicular to field) is,

$$e = NBA\,\omega \sin\omega t$$

With $\omega = 2\pi f$

Peak emf, $e_0 = NBA\omega$

7. TRANSFORMER

A transformer is a device which converts low AC voltage into high AC voltage and vice-versa. It works on the principle of mutual induction. If N_p and N_s are the number of turns in primary and secondary coil, V_p and I_p are voltage and current in primary coil, then voltage V_s and current I_s in secondary coil will be,

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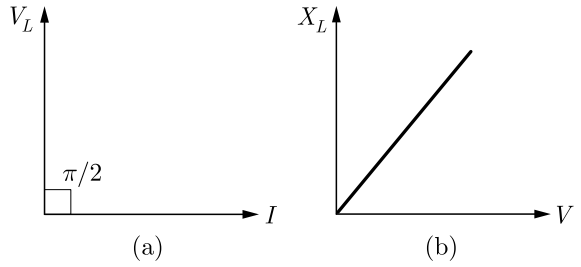
The inductive reactance increases with the increase of frequency of AC linearly [Figure (b)].



(a) (b)

5.3 Purely Capacitive Circuit

If circuit contains pure capacitance, then $\phi = \frac{\pi}{2}$, i.e., current leads the applied voltage by angle $\frac{\pi}{2}$.

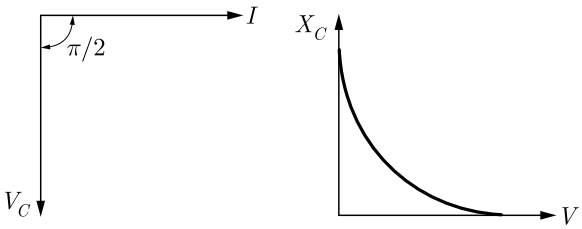
i.e., $V = V_0 \sin \omega t$

and $I = I_0 \sin\left(\omega t + \frac{\pi}{2}\right)$

Capacitive reactance,

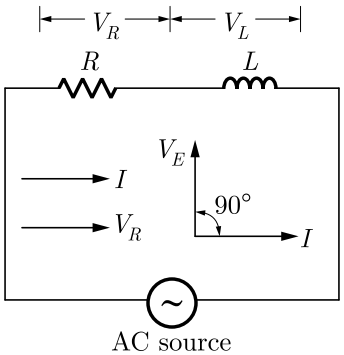
$$X_C = \frac{1}{\omega C}$$

Clearly, capacitive reactance (X_C) is inversely proportional to the frequency v [Figure (b)].

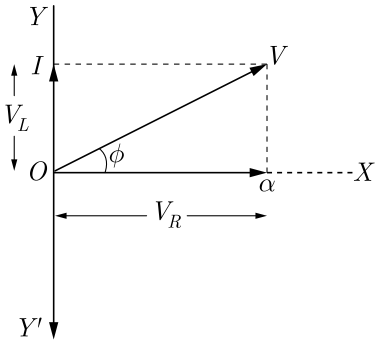


(a) (b)

5.4 In an L-R Series AC Circuit



(a)



(b)

Then,

1. Impedance,

$$Z = \sqrt{R^2 + X_L^2} = \frac{V_{rms}}{I_{rms}}$$

2. For the phase angle,

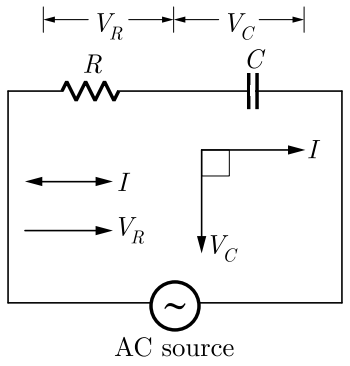
$$\tan \phi = \frac{X_L}{R} = \frac{\omega L}{R}$$

Voltage leads current by phase ϕ.

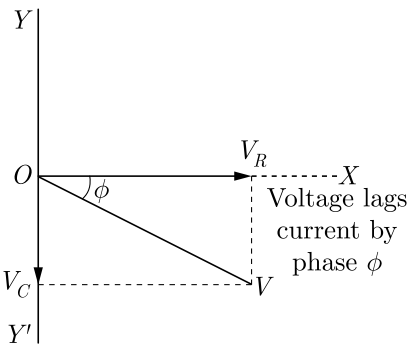
3. If $V = V_0 \sin \omega t$, then

$$I = I_0 \sin(\omega t - \phi)$$

5.5 In R-C Series AC Circuit



(a) Circuit diagram



(b) Phasor diagram

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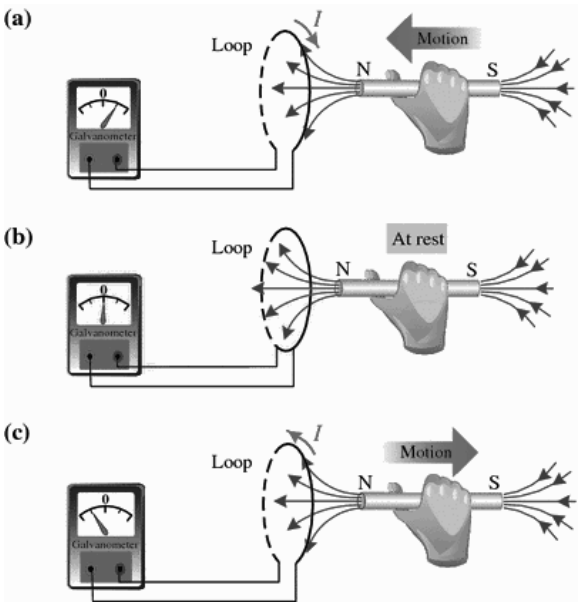


(i) Have you heard of a battery-less flashlight? How does it work?

(ii) Can you operate a typical cell phone from the hip movements of the person?

(iii) What do you know about gas-electric hybrid autos?

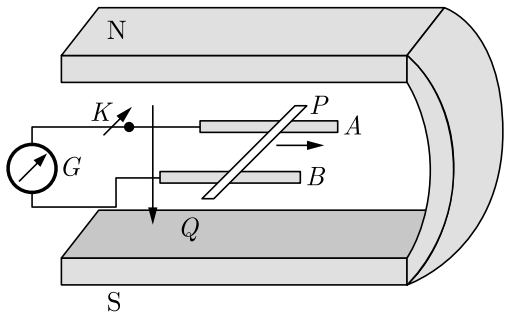
Ans :

(i) Yes, a flashlight without a battery can give us light for a few minutes. It is based on EMI. On shaking the flashlight, its permanent internal magnet passes through a coil, inducing some current. Thus, current is converted into AC and is used for charging a capacitor. The charged capacitor then send current through Light Emitting Diode (LED), which gives us light.

(ii) Yes, a backpack hybrids is used to convert the hip movements of the person into electricity and produce 7 W of electric power to operate a typical cell phone.

(iii) Gas electric hybrid autos are the latest innovations in the auto industry. The petrol engine is made smaller than the conventional one through the use of EMI some energy is supplied to batteries and electric motor. The purpose behind is to get more mileage for every litre of petrol consumed. This would make the auto cost effective.

142. Given figure shows a metal rod PQ resting on the smooth rails AB and positioned between the poles of a permanent magnet. The rails, the rod and the magnetic field are in three mutual perpendicular directions. A galvanometer G connects the rails through a switch K. Length of the rod $= 15$ cm, $B = 0.50$ T, resistance of the closed loop containing the rod $= 9.0\,\text{m}\Omega$. Assume the field to be uniform.



(a) Suppose K is open and the rod is moved with a speed of 12 cm s^{-1} in the direction shown. Give the polarity and magnitude of the induced emf.

(b) Is there an excess charge built up at the ends of the rods when K is open? What if K is closed?

(c) With K open and the rod moving uniformly, there is no net force on the electrons in the rod PQ even though they do experience magnetic force due to the motion of the rod. Explain.

(d) What is the retarding force on the rod when K is closed?

(e) How much power is required (by an external agent) to keep the rod moving at the same speed ($= 12$ cm/sec) when K is closed? How much power is required when K is open?

(f) How much power is dissipated as heat in the closed circuit? What is the source of this power?

(g) What is the induced emf in the moving rod if the magnetic field is parallel to the rails instead of being perpendicular?

Ans :

(a) $\text{EMF} = vBL$

$= 0.12 \times 0.50 \times 0.15$

$= 9.0\,\text{mV},$

P positive end and Q negative end.

(b) Yes. When K is closed, the excess charge is maintained by the continuous flow of current.

(c) Magnetic force is cancelled by the electric force set-up due to the excess charge of opposite signs at the ends of the rod.

(d) Retarding force $= IBL$

$9\,\text{mV}/9\,\text{m}\Omega \times 0.5\,\text{T} \times 0.15\,\text{m} = 75 \times 10^{-3} N$

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$$V_s = \left(\frac{N_s}{N_p}\right) V_p$$

and $$I_s = \left(\frac{N_p}{N_s}\right) I_p$$

Step up transformer increase the voltage while step down transfer decrease the voltage.

1. In step up transformer $V_s > V_p$, so $N_s > N_p$
2. In step down transformer $V_s < V_p$, so $N_s < N_p$
3. Efficiency of a transformer is given by,

$$\eta = \frac{V_s I_s}{V_p I_p}$$

OBJECTIVE QUESTIONS

1. Which of the following is not the characteristic of resonance in an LCR series circuit?

(a) $X_L = X_C$ (b) $\omega L = \frac{1}{\omega C}$

(c) $2\pi fL = 2\pi fC$ (d) $f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}$

Ans : **Main 2022 Sem-1**

In an LCR series circuit at resonance, inductive reactance equals capacitive reactance. The correct relation is $X_L = X_C$, which gives $\omega L = 1/\omega C$. The resonant frequency is $f = 1/(2\omega\sqrt{LC})$. Option (c) is incorrect because it wrongly states $2\omega fL = 2\omega fC$.Thus (c) is correct option.

2. The unit of reactance is

(a) Ohm (b) Farad

(c) Ampere (d) Mho

Ans : **Main 2017, 2016, 2013**

The property due to which a capacitor or inductor opposes the flow of electric current is known as reactance. The unit of reactance is Ohm.

Thus (a) is correct option.

3. Which one of the following statements is not true at resonance of a series L-C-R circuit?

(a) Reactance of the capacitor is equal to the reactance of the inductor.

(b) Impedance of the circuit is minimum.

(c) Current in the circuit is minimum.

(d) Current is in phase with supply voltage.

Ans : **Main 2022 Sem-I**

At resonance in a series LCR circuit, inductive reactance equals capacitive reactance, so impedance becomes minimum and current becomes maximum. The current and supply voltage are in phase. Therefore, the statement that current is minimum is not true.

Thus (c) is correct option.

4. Which of the following quantity is increased in a step-down transformer?

(a) current (b) voltage

(c) power (d) frequency

Ans : **Main 2001**

In a step-down transformer, the output voltage is decreased. As a result of this, the output current is increased.Thus (a) is correct option.

5. The best material for the core of a transformer is

(a) soft iron (b) mild steel

(c) hard steel (d) stainless steel

Ans : **Main 2013**

Transformer core is made by placing soft iron strips one above the other. These strips are insulated from each other to reduce eddy current.

Thus (a) is correct option.

6. An AC generator generating an emf of $\varepsilon = 300\sin(100\pi)t$ is connected to a series combination of 16 μF capacitor, 1 H inductor and 100 Ω resistor. What is the frequency of AC?

(a) 100 Hz (b) 50 Hz

(c) 300 Hz (d) 25 Hz

Ans : **Main 2022 Sem-1**

$$E = 300\sin(100\pi t)$$

$$\omega = 100\pi$$

$$2\pi f = 100\pi$$

$$f = 50\,\text{Hz}$$

Thus (b) is correct option.

7. If ϕ is the phase difference between AC current and *e.m.f.*, then the value of power factor is

(a) $\tan\phi$ (b) $\cos^2\phi$

(c) $\sin\phi$ (d) $\cos\phi$

Ans : **Main 2015**

Power factor is the magnitude of difference in the phase of voltage to current wave form. It is denoted by $\cos\phi$. Thus (d) is correct option.

8. A hot wire ammeter reads 10 A in an AC circuit. The peak value of the current is

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Ans : **Comp 2017**

$$I_{rms} = \sqrt{\frac{1}{T}\int_0^T I^2\,dt} \qquad ...(1)$$

Here, $I = I_0 \sin \omega t$

Now, $\int_0^T I^2\,dt = \int_0^T I_0 \sin^2 \omega t\,dt$

$$= I_0^2 \int_0^T \frac{1-\cos 2\omega t}{2}\,dt$$

$$= \frac{I_0^2}{2}\left[t - \frac{\sin 2\omega t}{2}\right]_0^T$$

$$= \frac{I_0^2}{2}\left[(t-0) - \frac{1}{2\omega}\left|\sin\frac{4\pi}{T}t\right|_0^T\right]$$

$$= \frac{I_0^2}{2}\left[T - \frac{1}{2\pi}(\sin 4\pi - \sin 0)\right]$$

$$= \frac{I_0^2 T}{2}$$

From equation (1), we get

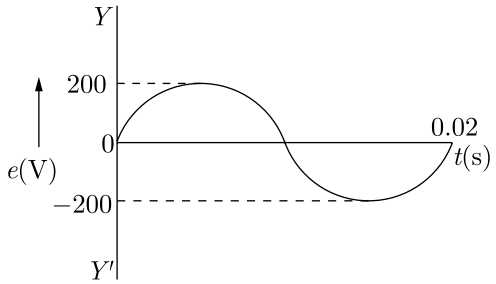
$$I_{rms} = \sqrt{\frac{1}{T} \times \frac{I_0^2 T}{2}}$$

$$I_{rms} = \frac{I_0}{\sqrt{2}}$$

$$I_0 = \sqrt{2}\, I_{rms}$$

Thus (a) is correct option.

48. The graph below shows how emf e generated by an AC generator varies with time t.



Mean value of the emf for the whole cycle is

(a) zero (b) $(400/\pi)$ V

(c) $(200\sqrt{2})$ V (d) $(200/\sqrt{2})$ V

Ans : **Main 2022 Sem-I**

$$V = V_0 \sin \omega t = 200 \sin \omega t$$

Mean value of emf for complete cycle ($t = 0$ to T),

$$V_{av} = \frac{\int_0^T V dt}{\int_0^T dt} = \frac{\int_0^T 200 \sin \omega t\,dt}{T}$$

$$= \frac{1}{T} \times 200 \int_0^T \sin \omega t\,dt$$

$$= \frac{200}{T}\left[\frac{-\cos \omega t}{\omega}\right]_0^T$$

$$= \frac{200}{\omega T}[\cos 0 - \cos \omega T]$$

$$= \frac{200}{2\pi}[1 - \cos 2\pi]$$

$$= \frac{200}{2\pi}[1-1] = 0$$

Thus (a) is correct option.

49. In an AC circuit, equation for the voltage is $V = 100 \sin(100\,t)$ volt and that for current is $(I) = 100 \sin(100t + \pi/3)$ mA. The power dissipated in the circuit is

(a) 2.5 W (b) 5 W

(c) 10 W (d) 20 W

Ans : **SQP 2011**

Equation of voltage,

$$V = 100 \sin(100\,t)$$

and equation of current,

$$I = 100 \sin(100t + \pi/3)\,\text{mA}$$

The standard equations of voltage and current are,

$$V = V_0 \sin(\omega t)$$

and $$I = I_0 \sin(\omega t + \phi)$$

Comparing the given equation with the standards equations, we get,

$$V_0 = 100\,\text{Vott}$$

$$I_0 = 100\,\text{mA} = 0.1\,\text{A}$$

and $$\phi = \frac{\pi}{3} = 60^\circ$$

Power dissipated in the circuit,

$$P = V_{\text{r.m.s.}} I_{\text{r.m.s.}} \cos\phi$$

$$= \frac{V_0}{\sqrt{2}} \times \frac{I_0}{\sqrt{2}} \times \cos\phi$$

$$= \frac{100}{\sqrt{2}} \times \frac{0.1}{\sqrt{2}} \times \cos 60^\circ$$

$$= 5 \times \frac{1}{2} = 2.5\,\text{W}$$

Thus (a) is correct option.

50. If L be the inductance, R resistance and C be the capacitance of a capacitor, then dimensional formulae of $\frac{L}{R}$ and RC are :

(a) $M^0LT^{-1}ML^0T^{-1}$ (b) M^0L^0T, MLT^0

(c) $M^0L^0T, 1$ (d) M^0L^0T, M^0L^0T

Ans : **SQP 2009**

Dimension of inductance,

$$L = \frac{\text{EMF}}{\text{current/time}}$$

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Ans : SQP 2015

Impedance of L-R circuit is given by,

$$Z = \sqrt{R^2 + X_L^2}$$

Here, $X_L = \omega L$

Hence, $Z = \sqrt{R^2 + (\omega L)^2}$

$= \sqrt{R^2 + \omega^2 L^2}$

Thus (d) is correct option.

16. The power factor of L-R circuit is

(a) $R + \omega L$ (b) $\dfrac{R}{\sqrt{R^2 + \omega^2 L^2}}$

(c) $R\sqrt{R^{2+}\omega^2}\, L^2$ (d) $\omega L/R$

Ans : SQP 2016

Power factor of L-R circuit is given by,

$$\cos\phi = \frac{R}{Z} = \frac{R}{\sqrt{R^2 + X_L^2}}$$

$$= \frac{R}{\sqrt{R^2 + (\omega L)^2}} \quad (\text{Since, } X_L = \omega L)$$

$$= \frac{R}{\sqrt{R^2 + \omega^2 L^2}}$$

Thus (b) is correct option.

17. The ratio of peak value and $r.m.s$ value of AC is

(a) 2 (b) $\sqrt{2}$

(c) $\dfrac{1}{\sqrt{2}}$ (d) $\dfrac{1}{2}$

Ans : Main 2015, 2010

The rms value of current is $\frac{1}{\sqrt{2}}$ times of the peak value of current i.e.,

$$I_{\text{rms}} = \frac{I_0}{\sqrt{2}}$$

$$\frac{I_0}{I_{\text{rms}}} = \sqrt{2}$$

where, I_0 = peak value of current

I_{rms} = rms value of current

Thus (b) is correct option.

18. The peak voltage of an AC is 440 volt. Its virtual voltage is

(a) 220 V (b) 440 V

(c) $220\sqrt{2}$ V (d) $440\sqrt{2}$ V

Ans : SQP 2012

$$V_{\text{rms}} = \frac{V_0}{\sqrt{2}}$$

Here, $V_0 = 440$ Volt

Hence, $V_{\text{rms}} = \dfrac{440}{\sqrt{2}} \times \dfrac{\sqrt{2}}{\sqrt{2}}$

$= 220\sqrt{2}$ Volt

Thus (c) is correct option.

19. An AC source of angular frequency ω is connected in a series LCR circuit. The peak value of current will be maximum when

(a) $\omega < \dfrac{1}{\sqrt{LC}}$ (b) $\omega < \sqrt{LC}$

(c) $\omega = \dfrac{1}{\sqrt{LC}}$ (d) $\omega > \dfrac{1}{\sqrt{LC}}$

Ans : Main 2010

For maximum value of current,

$$X_L = X_C$$

$$\omega L = \frac{1}{\omega C}$$

$$\omega^2 = \frac{1}{LC}$$

$$\omega = \frac{1}{\sqrt{LC}}$$

Thus (c) is correct option.

20. In an LCR series AC circuit, the voltage across each of the components, L, C and R is 50 V. The voltage across the LC combination will be

(a) zero (b) 50 V

(c) $50\sqrt{2}$ V (d) 100 V

Ans : SQP 2025

Voltage across inductor, $V_L = 50$ Volt

Voltage across capacitor, $V_C = 50$ Volt

Voltage across resistance, $V_R = 50$ Volt

Voltage the LC combination

$= V_L - V_C = 50 - 50 = 0$

Thus (a) is correct option.

21. If a circuit consists of inductance L, capacitance C and resistance R, then the resonant frequency of an LCR-circuit is

(a) $\pi\sqrt{LC}$ (b) $2\pi\sqrt{LC}$

(c) $2\pi\sqrt{\dfrac{1}{\sqrt{LC}}}$ (d) $\dfrac{1}{2\pi\sqrt{LC}}$

Ans : SQP 2002

Inductance $= L$

Capacitance $= C$

and Resistance $= R$

resonant frequency of an LCR-circuit,

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32. A coil of resistance $300\,\Omega$ and inductance 3 H is connected across an AC source of frequency $\frac{100}{2\pi}$ Hz. The phase difference between the voltage and current in the circuit is

(a) 30° (b) 45°

(c) 60° (d) 90°

Ans : SQP 2004

Resistance of coil, $R = 300\,\Omega$

Inductance of coil, $L = 3\,\text{H}$

Frequency, $f = \dfrac{100}{2\pi}\,\text{Hz}$

Angular frequency of AC source,

$$\omega = 2\pi f = 2\pi \times \frac{100}{2\pi}$$
$$= 100\,\text{rad-s}^{-1}$$

We also know that phase difference between the voltage and current in the LR-circuit,

$$\phi = \tan^{-1}\left(\frac{\omega L}{R}\right)$$
$$= \tan^{-1}\left(\frac{100 \times 3}{300}\right)$$
$$= \tan^{-1}(1) = 45^\circ$$

Thus (b) is correct option.

33. An alternating current of 1.5 mA and angular frequency $300\,\text{rad-s}^{-1}$ flews through $10\,\text{K}\Omega$ resistor and $0.5\,\mu\text{F}$ capacitor in series. The r.m.s voltage across the capacitor is

(a) 5 V (b) 10 V

(c) 20 V (d) 40 V

Ans : Main 2012

R.M.S. value of alternating current,

$$I_{\text{r.m.s.}} = 1.5\,\text{mA}$$

Angular frequency, $\omega = 300\,\text{rad-s}^{-1}$

Resistance of resistor,

$$R = 10\,\text{K}\Omega = 10 \times 10^3\,\Omega$$

and capacitance of capacitor,

$$C = 0.5\,\mu\text{F} = 0.5 \times 10^{-6}\,\text{F}$$

Reactance of the capacitor,

$$X_C = \frac{1}{\omega C}$$
$$= \frac{1}{300 \times (0.5 \times 10^{-6})}$$
$$= 6.67 \times 10^3\,\Omega$$

Therefore, r.m.s. voltage across capacitor,

$$V_C = I_{\text{rms}} \times X_C$$
$$= (1.5 \times 10^{-3})(6.67 \times 10^3)$$
$$= 10\,\text{Volt}$$

Thus (b) is correct option.

34. A circuit consists of a resistor, an inductor and a capacitor connected in series. If resistance of the resistor is $25\,\Omega$ and the value of inductive reactance is equal to capacitive reactance, then net impedance of the circuit will be

(a) $5\,\Omega$ (b) $25\,\Omega$

(c) $125\,\Omega$ (d) $625\,\Omega$

Ans : Main 2014, 2009

Resistance, $R = 25\,\Omega$

Inductive reactance = capacitive reactance

i.e., $X_L = X_C$

Net impedance of the LCR-circuit,

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$
$$= \sqrt{(25)^2 + (X_L - X_L)^2}$$
$$= 25\,\Omega$$

Thus (b) is correct option.

35. In an experiment, 200 V AC is applied at the ends of an LCR-circuit. The circuit consists of an inductive reactance of $50\,\Omega$, capacitive reactance of $35\,\Omega$ and ohmic resistance of $20\,\Omega$. The impedance of the circuit is

(a) $15\,\Omega$ (b) $25\,\Omega$

(c) $35\,\Omega$ (d) $45\,\Omega$

Ans : SQP 2008

Supply voltage, $V = 200\,\text{Volt}$

Inductive reactance,

$$X_L = 50\,\Omega$$

Capacitive reactance,

$$X_C = 35\,\Omega$$

Ohmic resistance, $R = 20\,\Omega$

Impedance of the LCR-circuit,

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$
$$= \sqrt{(20^2) + (50 - 35)^2}$$
$$= \sqrt{400 + 225}$$
$$= \sqrt{625}$$
$$= 25\,\Omega$$

Thus (b) is correct option.

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Ans : SQP 2017

Electric current, $I = 0.6 \sin 100\pi t$ ...(1)

The standard equation of electric current is given by,

$$I = I_0 \sin \omega t \quad ...(2)$$

After comparing equation (1) and (2), we get

$$\omega = 100\,\pi$$

Since, $\omega = 2\pi f$

Now, $2\,\pi f = 100\,\pi$

$$= \frac{100}{2} = 50 \text{ Hz}$$

Thus (b) is correct option.

28. The value of current flowing through an inductor of inductance 1 H and having negligible resistance when connected to an AC source of 200 V and 50 Hz is

(a) 0.64 A (b) 1.64 A

(c) 2.64 A (d) 3.64 A

Ans : Main 2014, 2012

Inductance, $L = 1$ H

Voltage, $V = 200$ Volt

Frequency, $f = 50$ Hz

Angular frequency,

$$\omega = 2\pi f = 2 \times 3.14 \times 50$$
$$= 314 \text{ rad-s}^{-1}$$

Therefore, reactance of the inductor,

$$X_L = \omega L = 314 \times 1 = 314\,\Omega$$

We also know that current flowing through the inductor,

$$I = \frac{V}{X_L} = \frac{200}{314} = 0.64 \text{ A}$$

Thus (a) is correct option.

29. Reactance of a capacitor of capacitance C for an alternating current of frequency $\frac{400}{\pi}$ Hz is $25\,\Omega$. The value of C is

(a) $25\,\mu$F (b) $50\,\mu$F

(c) $75\,\mu$F (d) $100\,\mu$F

Ans : Main 2004

Capacitance of capacitor $= C$

Frequency of current, $f = \frac{400}{\pi}$Hz

Reactance of capacitor, $X_C = 25\,\Omega$

Reactance of the capacitor,

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$$

$$C = \frac{1}{2\pi f X_C}$$

$$= \frac{1}{2\pi \times \frac{400}{\pi} \times 25}$$

$$= 50 \times 10^{-6}$$

$$F = 50\,\mu\text{F}$$

Thus (b) is correct option.

30. In an AC circuit, the potential difference across an inductance and resistance joined in series are 15 V and 25 V respectively.

(a) 15 V (b) 20 V

(c) 25 V (d) 50 V

Ans : Main 2009

Potential difference across the inductance,

$$V_L = 15 \text{ Volt}$$

and potential difference across the resistance,

$$V_R = 20 \text{ Volt}$$

Total potential difference across LR-circuit,

$$V = \sqrt{(V_L)^2 + (V_R)^2}$$
$$= \sqrt{(15)^2 + (20)^2}$$
$$= \sqrt{625} = 25 \text{ Volt}$$

Thus (c) is correct option.

31. The impedance of a circuit, when a resistance R and an inductor of inductance L are connected in series in an AC circuit of frequency f is

(a) $\sqrt{R + 2\pi^2 f^2 L^2}$ (b) $\sqrt{R + 4\pi^2 f^2 L^2}$

(c) $\sqrt{R^2 + 4\pi^2 f^2 L^2}$ (d) $\sqrt{R^2 + 2\pi^2 f^2 L^2}$

Ans : SQP 2024

Resistance $= R$

Inductance $= L$

and Frequency of current $= f$

Angular frequency of AC source,

$$\omega = 2\pi f$$

We also know that impedance of the circuit

$$Z = \sqrt{R^2 + (X_L)^2}$$
$$= \sqrt{R^2 + (\omega L)^2}$$
$$= \sqrt{R^2 + (2\pi f L)^2}$$
$$= \sqrt{R^2 + 4\pi^2 f^2 L^2}$$

Thus (c) is correct option.

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(a) 5πA (b) $10\sqrt{2}$ A

(c) $\frac{10}{\sqrt{2}}$A (d) $\frac{5}{\sqrt{2}}$A

Ans : SQP 2015

Given,

Reading of hot wire ammeter or r.m.s. value of current,

$$I_{\text{r.m.s.}} = 10 \text{ A}$$

Peak value of current,

$$I_0 = \sqrt{2} \times I_{\text{r.m.s.}}$$
$$= \sqrt{2} \times 10$$
$$= 10\sqrt{2} \text{ A}$$

Thus (b) is correct option.

9. Alternating current can not be measured by DC ammeter, because

(a) AC changes direction.

(b) DC ammeter will get damaged.

(c) AC can not pass through DC ammeter.

(d) average value of current for a complete cycle is zero.

Ans : SQP 2013

Alternating current can not be measured by DC ammeter, because average value of the current for a complete cycle is zero. That is why, DC ammeter records zero reading.

Thus (d) is correct option.

10. In a circuit, the current lags behind the voltage by a phase difference of $\frac{\pi}{2}$ radians. The circuit contains which of the following?

(a) only R (b) only L

(c) only C (d) R and C

Ans : SQP 2009, 2007

In an AC circuit containing only inductance L, the current lags behind the voltage by a phase difference of $\frac{\pi}{2}$ radians.

Thus (b) is correct option.

11. In an AC circuit containing only capacitor, the current

(a) leads the voltage by 90°.

(b) leads the voltage by 180°.

(c) lags behind the voltage by 90°.

(d) remains in phase with the voltage.

Ans : Main 2015

In an AC circuit containing only capacitor, the current leads the voltage by $\frac{\pi}{2}$ radians ($i.e., 90^\circ$). Thus (a) is correct option.

12. The value of peak AC in a 220 V mains is

(a) 220 V (b) $110\sqrt{2}$ V

(c) $220\sqrt{2}$ V (d) $440\sqrt{2}$ V

Ans : Main 2008

R.M.S. voltage, $V_{\text{r.m.s.}} = 220$ Volt

Value of peak voltage of AC,

$$V_0 = \sqrt{2} \times V_{\text{r.m.s.}}$$
$$= \sqrt{2} \times 220$$
$$= 220\sqrt{2} \text{ Volt}$$

Thus (c) is correct option.

13. In a purely resistive AC circuit, the current

(a) is in phase with the e.m.f.-

(b) leads the e.m.f. by a difference of π radians phase.

(c) leads the e.m.f. by a phase difference of $\frac{\pi}{2}$ radians.

(d) lags behind the e.m.f. by phase difference of $\frac{\pi}{4}$ radians.

Ans : SQP 2012

In a purely resistive AC circuit, the current is in phase with the e.m.f. (i.e., angle between current and e.m.f. is 0°).Thus (a) is correct option.

14. If N_1 and N_2 are numbers of turns in primary and secondary coils of a step-up transformer. Then

(a) $N_1 > N_2$ (b) $N_2 > N_1$

(c) $N_1 = N_2$ (d) $N_1 = 0$

Ans : Main 2016

In Step up transformer, $N_2 > N_1$ i.e., the turns ratio is greater than 1 and therefore $e_2 > e_1$. The output voltage is greater than input voltage.

Here, N_1 = number of turns in primary coil

N_2 = number of turns in secondary coil

Thus (b) is correct option.

15. Impedance of L-R circuit is :

(a) $R^2 + \omega^2 L^2$ (b) $\sqrt{R + \omega L}$

(c) $R + \omega L$ (d) $\sqrt{R^2 + \omega^2 L^2}$

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36. In a series combination, $R = 300\,\Omega$, $L = 0.9\,\text{H}$, $C = 2\,\mu\text{F}$, $\omega = 1000\,\text{rad–s}^{-1}$. The impedance of the LCR circuit is

(a) $400\,\Omega$ (b) $500\,\Omega$

(c) $900\,\Omega$ (d) $1300\,\Omega$

Ans : Main 2017

Resistance, $R = 300\,\Omega$

Inductance, $L = 0.9\,\text{H}$

Capacitance, $C = 2\,\mu\text{F} = 2 \times 10^{-6}\,\text{F}$

Angular velocity, $\omega = 1000\,\text{rad} - \text{s}^{-1}$

Reactance of inductor,

$$X_L = \omega L$$
$$= 1000 \times 0.9 = 900\,\Omega$$

and reactance of capacitor,

$$X_C = \frac{1}{\omega C}$$
$$= \frac{1}{1000 \times (2 \times 10^{-6})}$$
$$= 500\,\Omega$$

Therefore, impedance of LCR-circuit

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$
$$= \sqrt{(300)^2 + (900 - 500)^2}$$
$$= \sqrt{90000 + 160000}$$
$$= \sqrt{250000} = 500\,\Omega$$

Thus (b) is correct option.

37. In a series LCR-circuit, resistance $R = 10\,\Omega$ and the impedance $Z = 20\,\Omega$. The phase difference between the current and the voltage is

(a) 30° (b) 45°

(c) 60° (d) 90°

Ans : Main 2014

Resistance, $R = 10\,\Omega$

Impedance, $Z = 20\,\Omega$

Impedance in the LCR-circuit,

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$
$$20 = \sqrt{(10)^2 + (X_L - X_C)^2}$$
$$400 = 100 + (X_L - X_C)^2$$
$$(X_L - X_C)^2 = 400 - 100 = 300$$
$$X_L - X_C = \sqrt{300} = 10\sqrt{3}$$

We also know that phase difference between current and voltage,

$$\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$$
$$= \tan^{-1}\left(\frac{10\sqrt{3}}{10}\right)$$
$$= \tan^{-1}(\sqrt{3}) = 60^\circ$$

Thus (c) is correct option.

38. In a LCR-circuit, the potential difference between the terminals of the inductance is 60 V, between terminals of the capacitor is 30 V and that between the terminals of the resistance is 40 V. The supply voltage will be

(a) 25 V (b) 50 V

(c) 100 V (d) 200 V

Ans : SQP 2015, 2012

Potential difference across inductance,

$$V_L = 60\,\text{Volt}$$

Potential difference across capacitor,

$$V_C = 30\,\text{Volt}$$

and potential difference across resistance,

$$V_R = 40\,\text{Volt}$$

Supply voltage in LCR-circuit,

$$V = \sqrt{V_R^2 + (V_L - V_C)^2}$$
$$= \sqrt{(40)^2 + (60 - 30)^2}$$
$$= \sqrt{1600 + 900}$$
$$= \sqrt{2500} = 50\,\text{Volt}$$

Thus (b) is correct option.

39. In an AC circuit, voltage applied is $V = 100\sin(100\,t)$. If impedance of the circuit is $110\,\Omega$ and phase difference between current and voltage is 60°, then power in the circuit is

(a) 55 W (b) 110 W

(c) 220 W (d) 330 W

Ans : Main 2024, 2010

Equation of voltage, $V = 220\sin(100\,t)$

Impedance of circuit, $Z = 110\,\Omega$

and Phase difference between current and voltage,

$$\phi = 60^\circ$$

The standard equation for the voltage is,

$$V = V_0\sin(\omega t)$$

Comparing the given equation with the standard equation, we get

$$V_0 = 220\,\text{Volt}$$

Therefore peak value of current,

$$I_0 = \frac{V_0}{Z} = \frac{220}{110} = 2\,\text{A}$$

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We also know that power in the circuit,

$$\begin{aligned} P &= V_{\text{r.m.s.}} I_{\text{r.m.s.}} \cos\phi \\ &= \frac{V_0}{\sqrt{2}} \times \frac{I_0}{\sqrt{2}} \times \cos\phi \\ &= \frac{220}{\sqrt{2}} \times \frac{2}{\sqrt{2}} \times \cos 60^\circ \\ &= 220 \times 0.5 = 110 \text{ W} \end{aligned}$$

Thus (b) is correct option.

40. In a ideal transformer, voltage and current in primary are 200 V and 2 A respectively. If voltage in the secondary is 2000 V, then current in the secondary is

(a) 20 A (b) 10 A

(c) 2 A (d) 0.2 A

Ans : SQP 2016

Voltage in primary, $V_P = 200$ Volt

Current in primary, $I_P = 2$ A

Voltage in secondary, $V_S = 2000$ Volt

Relation between currents and voltages in primary and secondary is,

$$\frac{I_P}{I_S} = \frac{V_S}{V_P}$$

$$I_S = I_P \times \frac{V_P}{V_S}$$

$$= 2 \times \frac{200}{2000} = 0.2 \text{ A}$$

where, $I_S =$ current in secondary

Thus (d) is correct option.

41. The ratio of number. of turns of primary coil to secondary coil in a transformer is 2:3. If a cell of 6 V is connected across the primary coil, then voltage across the secondary coil will be

(a) 3 V (b) 6 V

(c) 9 V (d) 12 V

Ans : Main 2008, 2005

Number of turns in primary,

$$N_P = 2\,\text{N}$$

Number of turns in secondary coil,

$$N_S = 3\,\text{N}$$

Supply voltage on primary coil ,

$$V_P = 6 \text{ Volt}$$

Relation between voltages and number of turns in primary and secondary is,

$$\frac{V_P}{V_S} = \frac{N_P}{N_S}$$

$$V_S = V_P \times \frac{N_S}{N_P}$$

$$= 6 \times \frac{3\,\text{N}}{2\,\text{N}} = 9 \text{ Volt}$$

Where, $V_S =$ voltage across secondary coil

Thus (c) is correct option.

42. A step-up transformer has transformation ratio of 5:3. What is the voltage in the secondary, if voltage in the primary is 60 V?

(a) 180 V (b) 100 V

(c) 60 V (d) 20 V

Ans : Main 2005

Number of turns in secondary,

$$N_S = 5\,\text{N}$$

Number of turns in primary,

$$N_P = 3\,\text{N}$$

Voltage in primary,

$$V_P = 60 \text{ Volt}$$

Relation between voltages and number of turns in primary and secondary is,

$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$

$$V_S = V_P \times \frac{N_S}{N_P}$$

$$= 60 \times \frac{5\,\text{N}}{3\,\text{N}} = 100 \text{ Volt}$$

Where, $V_S =$ voltage in secondary

Thus (b) is correct option.

43. A step-up transformer operates on a 230 V line supplies a current of 2 A. The ratio of primary and secondary winding is 1:25. The current in the primary is

(a) 15 A (b) 50 A

(c) 75 A (d) 125 A

Ans : SQP 2016

Voltage in primary, $V_P = 230$ Volt

Current in secondary, $I_S = 2$ A

Number of windings in primary,

$$N_P = N$$

Number of windings in secondary,

$$N_S = 25\,\text{N}$$

Relation between currents and number of turns in primary and secondary coil is,

$$\frac{I_P}{I_S} = \frac{N_S}{N_P}$$

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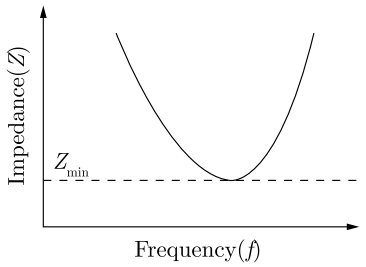
$$I_P = I_S \times \frac{N_S}{N_P}$$

$$= 2 \times \frac{25\,\text{N}}{N} = 50\ \text{A}$$

where, I_P = current in primary

Thus (b) is correct option.

44. A graph showing variation in impedance Z of a series LCR circuit, with frequency f of alternating emf applied to it is shown below. What is the minimum value of this impedance?



(a) R

(b) $Z = \sqrt{R^2 + (X_L - X_C)^2}$

(c) Z_{min}

(d) $X_L = X_C$

Ans : Main 2022 Sem-1, 2010

$$Z = \sqrt{\left(L\omega - \frac{1}{C\omega}\right)^2 + R^2}$$

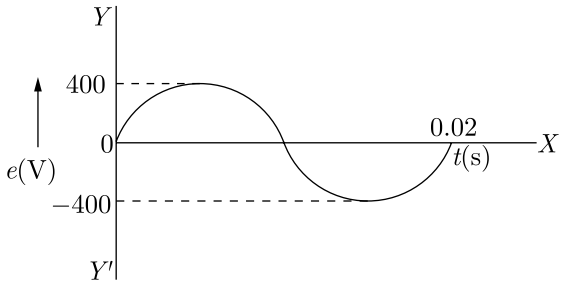
Z is minimum, when

$$L\omega = \frac{1}{C\omega}$$

$$Z = \sqrt{(0)^2 + (2)^2} \Rightarrow Z = R$$

Thus (a) is correct option.

45. If potential difference across a resistor of $80\,\Omega$ varies as shown in the graph below, average power consumed by the resistor is



(a) zero (b) 500 W

(c) 1000 W (d) 2000 W

Ans : Main 2022 Sem-I

Given $V_0 = 400$ Volt, $R = 80\,\Omega$

Purely resistive

$$\phi = 0$$

$$P_{\text{av}} = V_{\text{rms}} \cdot I_{\text{rms}} \cos\phi$$

$$= \frac{V_0}{\sqrt{2}} \cdot \frac{I_0}{\sqrt{2}} \cos\phi = \frac{1}{2} V_0 I_0 \cos\phi$$

$$= \frac{1}{2} V_0 \cdot \frac{V_0}{R} \cos\phi \qquad [V_0 = I_0 R]$$

$$= \frac{1}{2} \times \frac{400 \times 400}{80} \cos 0^\circ = 1000\ \text{W}$$

Thus (c) is correct option.

46. In an AC circuit, the equation of e.m.f is: $E = 4\cos(100t)$. The amplitude of current in an LR-circuit of inductance 0.03 H and resistance $4\,\Omega$ is

(a) $\frac{4}{\sqrt{7}}$ A (b) $\frac{4}{7}$ A

(c) 0.4 A (d) 0.8 A

Ans : Main 2001

Equation of e.m.f., $E = 4\cos(100t)$

Inductance, $L = 0.03$ H

Resistance, $R = 4\,\Omega$

The standard equation of e.m.f. in an AC circuit,

$$E = E_0 \cos(\omega t)$$

Comparing the given equation with the standard equation, we get:

$$E_0 = 4$$

and $\omega = 100$

We also know that impedance of LR-circuit,

$$Z = \sqrt{R^2 + (X_L)^2}$$

$$= \sqrt{R^2 + (\omega L)^2}$$

$$= \sqrt{R^2 + \omega^2 L^2}$$

$$= \sqrt{(4)^2 + [(100)^2 \times (0.03)^2]}$$

$$= \sqrt{16 + 9} = \sqrt{25} = 5\,\Omega$$

Therefore, amplitude of current in the circuit,

$$I_0 = \frac{E_0}{Z} = \frac{4}{5} = 0.8\ \text{A}$$

Thus (d) is correct option.

47. The relation between peak current, I_0 and root mean square current, I_{rms} is

(a) $I_0 = \sqrt{2}\, I_{\text{rms}}$ (b) $I_0 = I_{\text{rms}}$

(c) $I_0 = 2I_{\text{rms}}$ (d) $I_0 = \frac{I_{\text{rms}}}{\sqrt{2}}$

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$$f = \frac{1}{2\pi\sqrt{LC}}$$

Thus (d) is correct option.

22. Quality factor of LCR-circuit having resistance R and inductance L at resonance angular frequency ω is given by

(a) $\frac{\omega L}{R}$ (b) $\frac{R}{\omega L}$

(c) $\left(\frac{\omega L}{R}\right)^{1/2}$ (d) $\left(\frac{\omega L}{R}\right)^{2}$

Ans : **Main 2010**

Resistance $= R$ and Inductance $= L$.

and resonance angular frequency $= \omega$.

applied e.m.f. $= IR$.

and potential difference developed across the inductance $= I\omega L$

Therefore, quality factor,

$$Q = \frac{I\omega L}{IR} = \frac{\omega L}{R}$$

Thus (a) is correct option.

23. For an AC circuit, average power is 60 W. What will be the power factor for the same circuit, if its apparent power is 100 W ?

(a) 0.6 (b) 1.6

(c) 2.4 (d) 3.2

Ans : **SQP 2007**

Given,Average power $= 60$ W

and Apparent power $= 100$ W

Power factor, $\cos\phi = \frac{\text{Average power}}{\text{Apparent power}}$

$$= \frac{60}{100} = 0.6$$

Thus (a) is correct option.

24. The core of a transformer is laminated, so as to

(a) make it light weight

(b) make it robust and strong

(c) increase the secondary voltage

(d) reduce energy loss due to eddy current

Ans : **SQP 2011**

The varying magnetic flux link through a metallic conductor, sets up eddy current in the conductor and this eddy current is converted into heat energy which leads to the wastage of energy.

That is why, the core of a transformer is laminated to reduce the eddy current so as to reduce the energy loss.

Thus (d) is correct option.

25. An alternating current is given by: $I = I_1\cos\omega t + I_2\sin\omega t$. The root mean square current is given by

(a) $\frac{(I_1 + I_2)}{\sqrt{2}}$ (b) $\frac{(I_1 + I_2)^2}{2}$

(c) $\sqrt{\frac{I_1^2 + I_2^2}{2}}$ (d) $\sqrt{\frac{I_1^2 + I_2^2}{2}}$

Ans : **Main 2014**

Equation of alternating current,

$$I = I_1\cos\omega t + I_2\sin\omega t$$

Resultant or maximum current,

$$I_0 = \sqrt{I_1^2 + I_2^2}$$

Therefore, r.m.s. current,

$$I_{\text{r.m.s.}} = \frac{I_0}{\sqrt{2}}$$

$$= \frac{\sqrt{I_1^2 + I_2^2}}{\sqrt{2}}$$

$$= \sqrt{\frac{I_1^2 + I_2^2}{2}}$$

Thus (c) is correct option.

26. In AC circuit, the current and voltage are given by $i = 5\cos\omega t$ and $V = 200\sin\omega t$ respectively. Power loss in the circuit is

(a) 20 W (b) 40 W

(c) 1000 W (d) Zero

Ans : **Main 2024**

Given $i = 5\cos\omega t$

$$= 5\sin\left(\omega t + \tfrac{\pi}{2}\right)$$

and $V = 200\sin\omega t$

Power loss in circuit,

$$p = (V_{\text{rms}} \cdot i_{\text{rms}})$$

Where, θ is the phase difference between current and voltage.

$$\theta = \frac{\pi}{2} - 0 = \frac{\pi}{2}$$

Hence, $P = (V_{\text{rms}} \cdot i_{\text{rms}})$

$P = 0$ (Since, $\cos\frac{\pi}{2} = 0$)

Thus (d) is correct option.

27. If the equation of an electric current is $I = 0.6\sin 100\pi t$, the frequency of electric current is

(a) $50\,\pi$ (b) 50

(c) $100\,\pi$ (d) 100

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$$= \frac{[ML^2T^{-3}A^{-1}]}{(AT^{-1})}$$
$$= [ML^2T^{-2}A^{-2}] \quad ...(1)$$

Dimension of resistance,

$$R = \frac{\text{Potential difference}}{\text{current}}$$
$$= \frac{ML^2T^{-3}A^{-1}}{A}$$
$$= [ML^2T^{-3}A^{-2}] \quad ...(2)$$

Dimension of capacitance,

$$C = \frac{\text{Charge}}{\text{Potential difference}}$$
$$= \frac{AT}{ML^2T^{-3}A^{-1}}$$
$$= [M^{-1}L^{-2}T^4A^2] \quad ...(3)$$

After dividing equation (1) by equation (2), we get

$$\frac{L}{R} = \frac{[ML^2T^{-2}A^{-2}]}{[ML^2T^{-3}A^{-2}]}$$
$$= [T] = [M^0L^0T]$$

After multiplying equation (2) with (3), we get

$$RC = [ML^2T^{-3}A^{-2}][M^{-1}L^{-2}T^4A^2]$$
$$= [T] = [M^0L^0T]$$

Thus (d) is correct option.

51. A 2 μF capacitor, 100 Ω resistor and 8 H inductor are connected in series with an AC source. At a certain frequency of about 40 Hz for this AC source, the current drawn in the circuit is maximum. If the peak value of emf of the source is 200 V

(i) What is the peak value of current in the circuit?

(a) 1.4 A (b) 2.2 A

(c) 2.0 A (d) 1.8 A

(ii) What is the phase relation between voltages across inductor and resistor?

(a) $\pi/2$ radian (b) $\pi/3$ radian

(c) $\pi/4$ radian (d) π radian

(iii) What is the phase difference between voltages across inductor and capacitor?

(a) $\pi/2$ radian (b) $\pi/3$ radian

(c) $\pi/4$ radian (d) π radian

Ans : **Main 2022 Sem-I**

(i) (c) 2.0 A

$$C = 2\,\mu F = 2 \times 10^{-6}\,F$$
$$R = 100\,\Omega,\ L = 8\,H,$$
$$\varepsilon_0 = 200\,V,\ I_0 = ?,$$
$$X_L = ?,\ X_C = ?,\ Z = ?$$
$$v = v_r = \frac{1}{2\pi\sqrt{LC}}$$
$$= \frac{1}{2 \times 3.14\sqrt{8 \times 2 \times 10^{-6}}}$$
$$= \frac{1000}{8 \times 3.14} = 39.8\,Hz$$

Peak value of current

$$I_0 = \frac{E_0}{K} = \frac{200}{100} = 2\,A$$

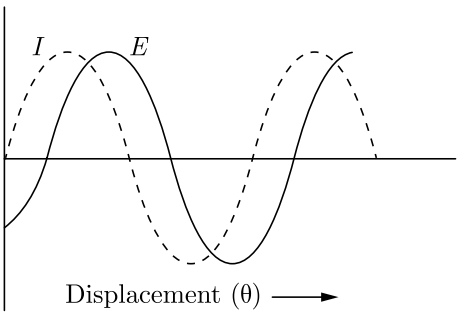
(ii) (a) $\pi/2$ radian

The voltage across inductor is ahead of voltage across resistor by a phase angle of 90°.

(iii) (d) π radian

The voltages across inductor and capacitor differ in phase by 180°.

52. When an AC source of e.m.f. $E = E_0\sin(100t)$ is connected across a circuit, the phase difference between the e.m.f. E and the current I in the circuit is observed to be $\frac{\pi}{4}$ rad, as shown in the diagram. If the circuit consists possibly only of RC or RL or LC in series, then relationship between the two elements is



(a) $R = 1\,k\Omega,\ C = 1\,\mu F$

(b) $R = 1\,K\Omega,\ L = 1\,H$

(c) $R = 1\,K\Omega,\ C = 10\,\mu F$

(d) $R = 1\,K\Omega,\ L = 10\,H$

Ans : **Comp 2003, 2005**

Equation for e.m.f., $E = E_0\sin(100t)$

and phase difference between e.m.f. and current,

$$\phi = \frac{\pi}{4}\text{rad}$$
$$= 45^\circ$$

The standard equation of e.m.f. of AC source,

$$E = E_0\sin(\omega t)$$

TWO MARKS QUESTIONS

85. Write any two sources of energy loss in a transformer.

Ans : SQP 2011

The sources of energy loss in a transformer are

(i) eddy current losses due to iron core,

(ii) flux leakage losses,

(iii) copper losses due to heating up of copper wires,

(iv) Hysteresis losses due to magnetisation and demagnetisation of core.

86. State the factors on which induced e.m.f. in a coil rotating in a uniform magnetic field depends.

Ans : Comp 2016

Since magnitude of induced e.m.f. is given by,

$$e = n\text{BA}\omega$$

So induced e.m.f. depends upon

1. Number of turns of the coil (n).
2. Face area of the coil (A).
3. Magnetic field strength (B).
4. The angular velocity of the coil (ω).

87. In any AC circuit, is the applied instantaneous voltage equal to the algebraic sum of the instantaneous voltages across the series elements of the circuit? Is the same true for rms voltage?

Ans : Comp 2013

Yes, in any AC circuit, the applied instantaneous voltage is equal to the algebraic sum of instantaneous voltage across the series elements, because instantaneous voltages are in the same phase.

This is not true in the case of rms voltages, because they are usually not in the same phase.

88. What is transformer? What do you mean by its efficiency?

Ans : Comp 2019

Transformer is a device, which is used to increase or decrease the alternating voltage.

Efficiency of Transformer : The ratio of output power to input power is known as efficiency of transformer

$$\eta = \frac{\text{Power output}}{\text{Power input}}$$

The efficiency, $$\eta = \frac{\text{Power output}}{\text{Power input}} \times 100\%$$

The efficiency of real transformers is fairly high (90-99%) through not 100%.

89. State the underlying principle of a transformer. How is the large scale transmission of electric energy over long distance done with the use of transformers?

Ans : SQP 2014

Principle of Transformer : A transformer is based on the principle of mutual induction, i.e., whenever the amount of magnetic flux linked with a coil changes, an emf is included in the neighbouring coil.

Power Transmission : Electric power is transmitted over long distances at high voltage. So step-up transformers are used at power stations to increase the voltage of power whereas a series of step-down transformers are used to decrease the voltage upto 220 V.

90. State the principle of working of a transformer. Can a transformer be used to step-used to step-up or step-down a DC voltage? Justify your answer.

Ans : Main 2025

Working of a transformer is based on the principle of mutual induction. Transformer cannot step-up or step-down a DC voltage.

Reason : No change in magnetic flux.

Explanation : When DC voltage source is applied across a primary coil of a transformer, the current in primary coil remains same, so there is no change in magnetic flux associated with it and hence no voltage is induced across the secondary coil.

91. Prove that an ideal capacitor in an AC circuit does not dissipate power.

Ans : Main 2018

Since, average power consumption in an AC circuit is given by,

$$P_{av} = V_{rms} \times I_{rms} \times \cos\phi$$

But in pure capacitive circuit, phase difference between voltage and current is,

$$\phi = \frac{\pi}{2}$$

Hence, $$P_{av} = V_{rms} \times I_{rms} \times \cos\frac{\pi}{2}$$

$$P_{av} = 0 \qquad \left(\text{since } \cos\frac{\pi}{2} = 0\right)$$

Thus, no power is consumed in pure capacitive AC circuit.

92. Explain why current flows through an ideal capacitor when it is connected to an AC source, but not when it connected to a DC source in a steady state.

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$$= 20 \times \frac{2\,\text{N}}{N} = 40\,\text{Volt}$$

where, V_P = input voltage in primary

Thus (b) is correct option.

55. A 220 V, 50 Hz AC source is connected to a series combination of a 3.16 μF capacitor, a 0.63 H inductor and a 600 Ω resistor. Then, (approximately)

(i) Reactance of the capacitor is

(a) 1000 Ω (b) 900 Ω

(c) 1 Ω (d) 0.1 Ω

(ii) Reactance of the inductor is

(a) 400 Ω (b) 300 Ω

(c) 200 Ω (d) 100 Ω

(iii) Impedance of the circuit is

(a) 800 Ω (b) 1000 Ω

(c) 1200 Ω (d) 1400 Ω

(iv) Phase difference between the current and the supply voltage is

(a) 53°, with current leading oven supply voltage

(b) 53°, with current lagging behind supply voltage

(c) 37°, with current lagging behind supply voltage

(d) 37°, with current leading over supply voltage

Ans : **Main 2022 Sem-I**

$$f = 50\,\text{Hz},\ R = 600\,\Omega,$$
$$C = 3.16\,\mu\text{F} = 3.16 \times 10^{-6}\,\text{F},$$
$$L = 0.63\,\text{H}$$

(i) (a) 1000 Ω

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$$
$$= \frac{1}{2\pi \times 50 \times 3.16 \times 10^{-6}}$$
$$= 1000\,\Omega$$

(ii) (c) 200 Ω

$$X_L = \omega L = 2\pi f L = 2\pi \times 50 \times 0.63$$
$$= 2\pi \times 50 \times \frac{2}{\pi} = 200\,\Omega$$

(iii) (b) 1000 Ω

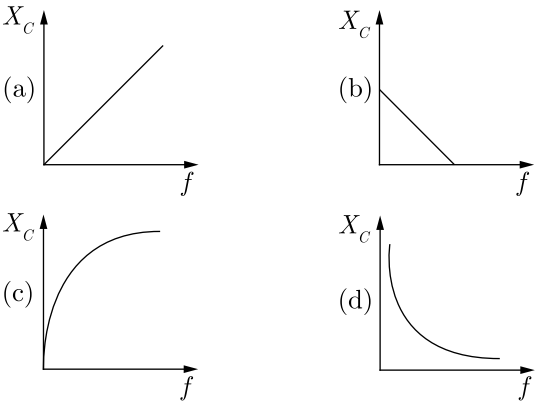
$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$
$$= \sqrt{600^2 + (200 - 1000)^2} = 1000\,\Omega$$

(iv) (a) 53°, with current leading oven supply voltage

$$\tan\phi = \left|\frac{X_L - X_C}{R}\right|$$
$$= \left|\frac{200 - 1000}{600}\right|$$
$$= \left|\frac{-800}{600}\right| = \left|-\frac{4}{3}\right|$$
$$\tan\phi = \frac{4}{3}$$
$$\phi = \tan^{-1}\left(\frac{4}{3}\right) = 53^\circ$$

Current leads the voltage by 53° $(X_C > X_L)$

56. Which one of the following graph in figure represents variation of reactance X_C of a capacitor with frequency of f of an AC supply ?



Ans : **Main 2012, 2007**

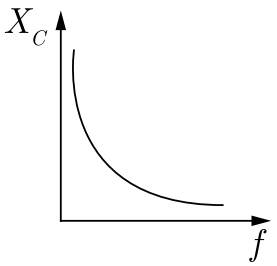
Reactance (X_C) of a capacitor is given by

$$X_C = \frac{1}{\omega C}$$
$$X_C = \frac{1}{(2\pi f)\,C}$$

where, C is capacitance and f is frequency.

So, $X_C \propto \frac{1}{f}$ [C is constant]

The graph will be rectangular hyperbola as shown below.



Thus (d) is correct option.

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Comparing the given equation with the standard equation, we get

$$\omega = 100 \text{ rad-s}^{-1}$$

We also know from the given figure that the current leads e.m.f. by,

$$\frac{\pi}{4} \text{ rad} = 45^\circ$$

Therefore circuit consists of only RC-circuit, in which the phase difference,

$$\theta = \tan^{-1}\left(\frac{1}{\omega CR}\right)$$

$$45^\circ = \tan^{-1}\left(\frac{1}{\omega CR}\right)$$

$$\left(\frac{1}{\omega CR}\right) = \tan 45^\circ = 1$$

$$\frac{1}{CR} = \omega = 100$$

$$CR = 10^{-2}$$

This condition is satisfied when,

$$R = 1\,\text{k}\Omega$$

and $$C = 10\,\mu\text{F}$$

Thus (c) is correct option.

53. When a capacitor, an inductor and a resistor are connected in series to an AC source,

(i) Average power consumed by the capacitor is

(a) $I^2 \times X_C$ (b) $I^2 \times C$

(c) $I^2 \times R$ (d) zero

(ii) Phase difference between potential difference across a capacitor and that across an inductor is

(a) 90°

(b) 180°

(c) $\tan^{-1}(X_L - X_C)/R$

(d) $\cos^{-1}(X_L - X_C)/R$

(iii) Current flowing through the circuit is maximum, when

(a) $X_L = X_C$ (b) $X_L > X_C$

(c) $X_L < X_C$ (d) $Z > R$

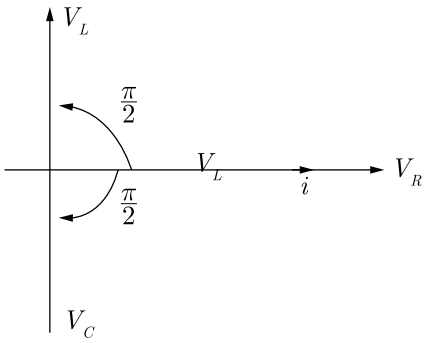
Ans : **Main 2022 Sem-I**

(i) (d) zero

P_{av} by capacitor $= VI\cos\frac{\pi}{2} = 0$

(ii) (b) 180°

For L-C-R circuit, $\pi/2$



Phase difference between V_L and

$$V_C = \frac{\pi}{2} + \frac{\pi}{2} = \pi = 180^\circ$$

(iii) (a) $X_L = X_C$

At resonance i.e., $X_L = X_C$ maximum current flows in a circuit.

54. In a transformer, the output current and voltage are respectively 4 A and 20 V. If ratio of number of turns in primary to secondary is 2 : 1, what is the input current and voltage?

(a) 1 A and 20 V (b) 2 A and 40 V

(c) 4 A and 80 V (d) 8 A and 160 V

Ans : **SQP 2003, 2000**

Output current in secondary,

$$I_S = 4 \text{ A}$$

Output Voltage in secondary,

$$V_S = 20 \text{ Volt}$$

Number of turns in primary, coil

$$N_P = 2\,\text{N}$$

and number of turns in secondary, coil

$$N_S = N$$

Relation between currents and number of turns in primary and secondary coil is,

$$\frac{I_P}{I_S} = \frac{N_S}{N_P}$$

$$I_P = I_S \times \frac{N_S}{N_P}$$

$$= 4 \times \frac{N}{2\,\text{N}}$$

$$= 2 \text{ A}$$

where, I_P = current in primary

We also know that relation between voltage and number of turns in primary and secondary coil is:

$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$

or $$V_P = V_S \times \frac{N_P}{N_S}$$

NODIA

60. **Assertion :** Ohm's law cannot be applied to a.c. circuit.

Reason : Resistance offered by capacitor for a.c. source depends upon the frequency of the source.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **SQP 2025**

Assertion is incorrect but Reason is correct.

Thus (d) is correct option.

61. **Assertion :** The resistance offered by an inductor in a d.c. circuit is always constant.

Reason : The resistance of inductor in steady state is non-zero.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **Main 2014**

Resistance offered by an inductor in a d.c. circuit at $t = 0$ is infinity, which decreases to zero at steady state.

Thus (d) is correct option.

62. **Assertion :** A laminated core is used in transformers to increase eddy currents.

Reason : The efficiency of a transformer increases with increase in eddy currents.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **SQP 2017**

Large eddy currents are produced in non-laminated iron core of the transformer by the induced emf, as the resistance of bulk iron core is very small. By using thin iron sheets as core the resistance is increased. Laminating the core substantially reduces the eddy currents. Eddy current heats up the core of the transformer. More the eddy currents greater is the loss of energy and the efficiency goes down.

Thus (d) is correct option.

ONE MARK QUESTIONS

63. A lamp is connected in series with an inductor and an AC source. What happen to the brightness of the lamp when the key is plugged in and an iron rod is inserted inside the inductor ? Explain

Ans : **Main 2015**

When an iron rod is inserted, the inductance increases due to which current decreases and hence the brightness decreases.

64. Why is core of transformer laminated?

Ans : **SQP 2018**

The alternating magnetic flux induces eddy currents in the iron core and causes heating. The effect is reduced by having a laminated core, because of its insulation properly.

65. What is wattless current?

Ans : **Main 2011**

When pure inductor and/or pure capacitor is connected to AC source, the current flows in the circuit, but with no power loss; the phase difference between voltage and current is $\frac{\pi}{2}$. Such a current is called the wattless current.

66. State any two characteristics of resonance in an L-C-R series circuit.

Ans : **Main 2025**

Characteristics of series resonant circuit

(a) The applied alternating voltage and the resulting current are in the same phase.

(b) The impedance Z of the circuit is minimum and is equal to the resistance R in the circuit.

67. Mention the two important properties of the material suitable for making core of a transformer.

Ans : **SQP 2017, 2015**

Two characteristic properties:

1. Low hysteresis loss
2. Low coercivity.

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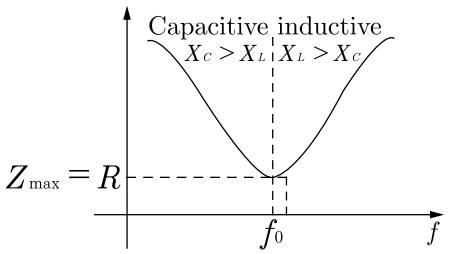
where, E = net emf of the circuit
R = Resistance in the circuit
X_L = Inductive reactance
ω = Angular frequency

THREE MARKS QUESTIONS

98. Plot a labelled graph showing variation in impedance Z of a series L-C-R circuit with frequency f of alternating emf applied to it. What is the minimum value of this impedance?

Ans : **Main 2010**

At $f = f_0$, $Z = R$. This is the minimum value of impedance.



99. What do you mean by lag and lead in alternating current?

Ans : **SQP 2012**

In a DC supply the e.m.f. and current are always in the same phase and there is nothing like 'lag' or 'lead' but in an AC supply, although the e.m.f. and current have the same frequency, yet they may be out of phase with each other, i.e. the peak value of e.m.f. and peak value of current may not occur at the same time. This brings in the idea of 'lag' and 'lead' in an AC circuit. If the peak value of e.m.f. occurs before the peak value of current, the e.m.f. is used to 'lead' the current is said to 'lag' behind the e.m.f. by a certain angle of fraction of the time period. The exact value of 'lag' or 'lead' depends on the nature of circuit.

100. An AC circuit with resistance R, inductance L and capacitance C are connected in series. The value of C is adjusted for resonance. State any three properties of this circuit which hold true for resonance only. (Give the properties in words or equations, relating
X_L, X_C, Z, R, ϕ, power, etc.)

Ans : **Main 2006**

At resonance, $X_L = X_C \Rightarrow \omega = \dfrac{1}{\sqrt{LC}}$

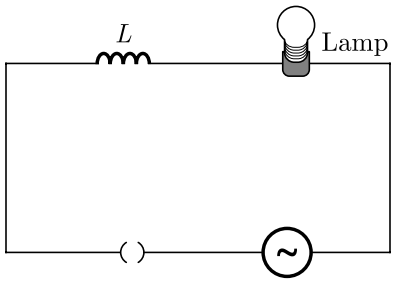
So, the circuit has following characteristics at resonance.

(i) Current in the circuit is maximum $\frac{\varepsilon_0}{R}$ or circuit impedance is minimum and purely resistive.

(ii) There is no phase difference between current and the applied voltage.

(iii) Power utilisation by the circuit is maximum. i.e. $\frac{\varepsilon_{rms}^2}{R}$.

101. When an AC source is connected to an ideal inductor show that the average power supplied by the source over a complete cycle is zero.



Ans : **SQP 2017**

Average power $P_{av} = I_{av} \times e_{av} \cos\phi$

For and ideal inductor, $\phi = \frac{\pi}{2}$ (The phase difference between voltage and current is $\frac{\pi}{2}$)

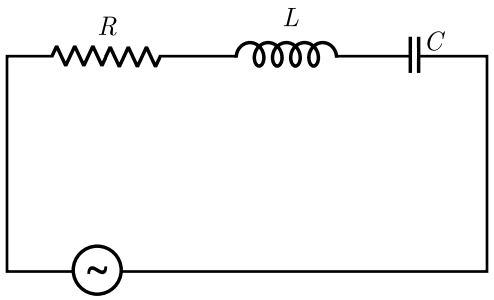
Hence, $P_{av} = I_{av} \times e_{av} \cos\dfrac{\pi}{2}$

$P_{av} = 0$

102. For circuits used for transporting electric power, a low power factor implies large power loss in transmission. Explain.

Ans : **SQP 2016**

The power is $P = V_{rms} I_{rms} \cos\phi$. If $\cos\phi$ is small, then current considerably increases when voltage is constant. As we know, power loss is I^2R. Hence, power loss increases.



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voltage because of

(i) the loss of energy in transmitting the AC voltage over long distance with the help of step-up transformers is negligible as compared to DC voltage.

(ii) AC voltage can be stepped up and stepped down as per the requirement by using a transformer.

79. Define Capacitor reactance. Write its SI units.

Ans : **Main 2025**

Capacitor reactance is the resistance offered by a capacitor, when it is connected to an electric circuit. It is given by,

$$X_C = \frac{1}{\omega C}$$

where, ω = angular frequency of the source

C = Capacitance of the capacitor

The SI unit of capacitor reactance is ohm (Ω).

80. An alternating current of frequency f is flowing through an ideal choke coil of self-inductance L. If V_0 and I_0 be the peak values of the voltage and current, then find the average power consumed, if any, by the choke coil.

Ans : **Main 2009**

Average power consumed

$$P_{av} = I_{rms} V_{rms} \cos\phi$$

For ideal choke coil, phase difference between current (I) and voltage (V) is $\frac{\pi}{2}$.

i.e. $\phi = 90^\circ$

$$\cos\phi = 0$$

$$P_{av} = V_{rms} I_{rms} \cos 90^\circ$$

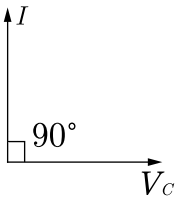
$$= (V_{rms} I_{rms})(0) = 0$$

Hence, no power consumed by an ideal choke coil.

81. Alternating current flowing through a certain electrical device leads over the potential difference across it by 90°. State whether this device is a resistor, capacitor or an inductor.

Ans : **Main 2013**

As, the current is leading over voltage, hence the device must be capacitor.

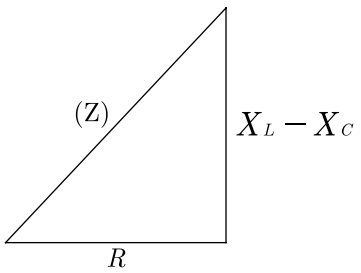


82. What is the power factor of a series L-C-R circuit?

Ans : **Main 2008**

If ϕ is the angle of lag or lead of emf or current in a series L-C-R circuit, then $\cos\phi$ component in the equation of power average is called power factor.

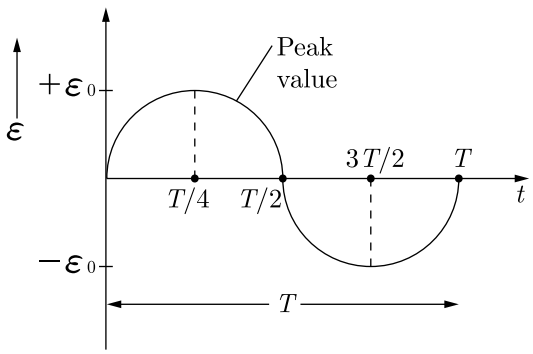
$$\cos\phi = \frac{R}{Z} = \frac{R}{\sqrt{\left(\omega L - \frac{1}{\omega L}\right)^2 + R^2}}$$



83. In a graphical variation of emf induced with time for the output of an AC generator, mark the peak value of emf induced and the time period.

Ans : **Main 2007**

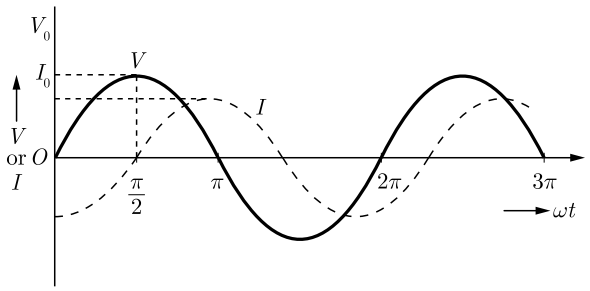
The graphical variation of emf induced with time for the output of an AC generator is shown as below.



84. An AC source of voltage $V = V_0 \sin\omega t$ is connected to an ideal inductor. Draw graphs of voltage V and current I versus ωt.

Ans : **Main 2021, 2018**

Graphs of V and i versus ωt for this circuit is shown below :



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57. A school organised an educational tour to two places. First one was to a thermal power station and the second one was to a factory manufacturing dry cells. The engineer at the power station explained to the students, how electric power is generated at the power station and how it is transmitted to the city. The manager at the factory took them around the factory and explained to them the importance of dry cells in our daily life.

(i) Voltages generated by the power station and the dry cell are

(a) DC voltage and AC voltage respectively

(b) AC voltage and DC voltage respectively

(c) Both AC voltages

(d) Neither AC voltages nor DC voltages

(ii) AC voltage generated all over the world has a frequency of about

(a) 50 Hz (b) 500 Hz

(c) 1000 Hz (d) 1500 Hz

(iii) Which one of the following statements is true?

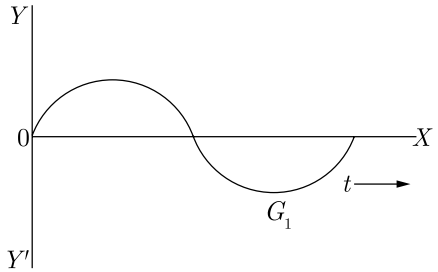
(a) DC voltage can be stepped up or down.

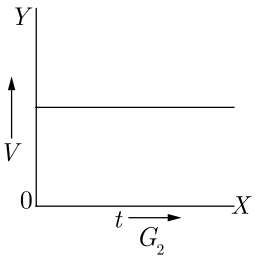
(b) AC voltage can be stepped up or down.

(c) Both DC and AC voltages can be stepped up or down.

(d) Neither AC nor DC voltage can be stepped up or down.

(iv) Refer to graphs G_1 and G_2 shown below and choose the correct option.





(a) Both represent AC voltage

(b) Both represent DC voltage

(c) G_1 represents AC voltage

(d) G_1 represents DC voltage

Ans : **Main 2022 Sem-I**

(i) (b) AC voltage and DC voltage respectively

(ii) (a) 50 Hz

(iii) (b) AC voltage can be stepped up or down.

(iv) (c) G_1 represents AC voltage

ASSERTION AND REASON

58. **Assertion :** In series LCR circuit resonance can take place.

Reason : Resonance takes place if inductance and capacitive resistances are equal and opposite.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **Main 2007**

In series resonance circuit, current becomes maximum because total impedance becomes zero. In case of LC circuit,

$$\text{Total impedance} = \omega L - \frac{1}{\omega C} = 0$$

$$\omega L = \frac{1}{\omega C}$$

$$\omega^2 = \frac{1}{LC}$$

Thus (a) is correct option.

59. **Assertion :** Long distance power transmission is done at high voltage.

Reason : At high voltage supply power losses are less.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **Main 2017**

$$\text{Power loss} = I^2R = \left(\frac{P}{V}\right)^2 R$$

[P = Transmitted power]

Thus (d) is correct option.

Ans : SQP 2016, 2013

For AC source, circuit is complete due to the presence of displacement current in the capacitor. For steady DC, there is no displacement current, therefore, circuit is not complete.

Mathematically, Capacitive reactance,

$$X_C = \frac{1}{2\pi fC} = \frac{1}{\omega C}$$

So, capacitor allows easy path for AC source.

For DC, $f = 0$

$$X_C = \text{infinity}$$

So, Capacitor block DC.

93. Define mean value and root mean square value of alternating current.

Ans : SQP 2024

Mean Value of Alternating Current, AC : It is defined as the value of AC which would send same amount of charge through a circuit in half cycle that is sent by steady current in the same time. It is denoted by I_m or I_{av}.

Root mean Square Value of AC : It is defined as that average value of alternating current (AC) over a complete cycle which would generate same amount of heat in a given resistor that is generated by steady current in the resistor and in the same time during a complete cycle.

94. The current flowing through a pure inductance 2 mH is $I = (15\cos 300t)\,A$. What is the (i) r.m.s. and (ii) average value of current for a complete cycle?

Ans : SQP 2021

Current flowing through the inductor,

$$I = 15\cos 300t$$

Comparing with $I = I_0 \sin \omega t$

Here, peak value of current,

$$I_0 = 15\text{ A}$$

(i) For complete cycle, rms value of current

$$I_{rms} = \frac{I_0}{\sqrt{2}} = \frac{15}{\sqrt{2}}\text{ A}$$

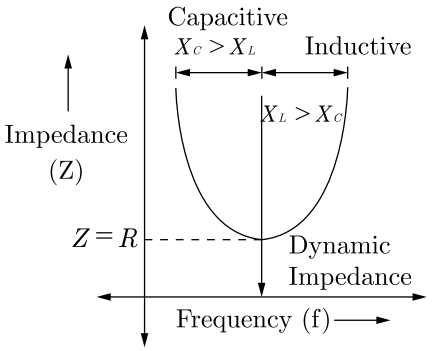
(ii) For complete cycle average value of current is zero

i.e., $I_{av} = 0$

95. Draw a labelled graph showing variation of impedance of a series L-C-R circuit with frequency of the AC supply.

Ans : Main 2015, 2011

The variation of impedance of a series L-C-R circuit with frequency of AC supply is given below:



96. What is transformer? What is transformation ratio?

Ans : Comp 2021

Transformer is a device, which is used to increase or decrease the alternating voltage.

The transformers are of the following types

1. Step-up transformer
2. Step-down transformer

Transformation Ratio : The transformation ratio is defined as the ratio of the secondary voltage (E_2) to primary voltage. (E_1) It is denoted by K.

$$K = \frac{E_2}{E_1} = \frac{N_2}{N_1}$$

where, N_1 and N_2 are the number of turns in primary and secondary coil.

1. If $N_2 > N_1$ i.e., $K > 1$, then transformer is called step-up transformer.
2. If $N_2 < N_1$ i.e., $K < 1$, then transformer is called step down transformer.

97. Write down the equation of induced current at any instant in L-C-R circuit when $X_L > X_C$ or circuit is inductive.

Ans : SQP 2021

Equation of induced current at any instant in LCR circuit is given by :

$$I = \frac{E}{Z}$$

where, $Z = \sqrt{R^2 + (X_L - X_C)^2}$ [Since, $X_L > X_C$]

$$I = \frac{E}{\sqrt{R^2 + (X_L - X_C)^2}}$$

Since, $X_L = \omega L$

and $X_C = \frac{1}{\omega C}$

$$I = \frac{E}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega c}\right)^2}}$$

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68. What is the value of power factor for a pure resistor connected to an alternating current source?

Ans : **Main 2019**

For pure resistor, phase difference between alternating current and alternating voltage,

$$\phi = 0^\circ$$

$$\text{Power factor} = \cos\phi = \cos 0^\circ = 1$$

69. Name the energy losses in a transformer.

Ans : **Main 2013**

Energy loss in transformers are :

1. Flux leakage
2. Resistance to the windings
3. Eddy currents
4. Hysteresis.

70. What is the function of a step-up transformer?

Ans : **SQP 2019**

Step-up transformer converts low alternating voltage into high alternating voltage and high alternating current into low alternating current. The secondary coil of step-up transformer has greater number of turns than the primary ($N_s > N_p$).

71. What is the function of a step-up transformer?

Ans : **SQP 2024**

Step-up transformer converts low alternating voltage into high alternating voltage and high alternating current into low alternating current. The secondary coil of step-up transformer has greater number of turns than the primary ($N_s > N_p$).

72. Give the expression for the power factor in an L-R circuit in terms of the resistance R and the inductive reactance X_L.

Ans : **Main 2002**

$$\text{Power factor} = \cos\phi = \frac{R}{Z} = \frac{R}{\sqrt{R^2 + X_L^2}}$$

$$\left[Z = (R^2 + X_L^2)^{1/2}\right]$$

73. What is inductive reactance?

Ans : **Comp 2015**

The opposing nature of inductor to flow of alternating current is called inductive reactance.

$$X_L = \omega L$$

$\omega =$ average frequency

$L =$ self Inductance

74. For circuit used for transporting electric power, a low power factor implies large power loss in transmission. Explain.

Ans : **Main 2013**

Since, Power factor, $\cos\phi = \frac{R}{Z}$

Where, $R =$ resistance and $Z =$ impedance. Low power factor ($\cos\phi$) implies lower ohmic resistance and higher power loss as $P_{av} \propto \frac{1}{R}$ in power system (transmission line.)

75. What is the value of power factor in a series of L-C-R circuit at resonance?

Ans : **Main 2009**

For a L-C-R series circuit, its defined as cosine of the angle of lag or lead or resistance/impedance.

i.e. power factor,

$$\cos\phi = \frac{R}{Z} = \frac{R}{\sqrt{(X_C - X_L)^2 + R^2}}$$

where, $Z =$ impedance

$$= \sqrt{(X_C - X_L)^2 + R^2}$$

At resonance, $X_C = X_L$

$$\cos\phi = 1$$

76. An ideal inductor does not consume any power even though both V and I are non-zero. Explain in brief.

Ans : **Main 2005, 2001**

Consumed power $P_{av} = V_{rms} I_{rms} \cos\phi$

For an ideal inductor, $\phi = 90^\circ$

(i.e. phase difference between V and I is $\frac{\pi}{2}$)

$$\cos\phi = 0$$

Consumed Power $P = (V_{rms})(I_{rms})(0) = 0$

77. Mention any two special properties of an L-C-R circuit at resonance.

Ans : **Main 2003**

(i) At resonance, $X_L = X_C$ i.e. $R = Z$, circuit behaves like a purely resistive circuit. Current and voltage are in phase.

(ii) At resonance, $Z = R(\min)$, $\cos\phi = 1$

$$P = I_{rms} V_{rms}$$

So, power utilisation in the circuit is maximum.

78. Why is the use of AC voltage preferred over DC voltage? Give two reasons.

Ans : **Comp 2021**

The use of AC voltage is preferred over DC

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The voltage $V = V_0 \sin \omega t$ is applied across the series LCR circuit. However due to impedance of the circuit either current lags or leads the voltage by phase opposite so the current in the circuit is given by $I = I_0 \sin(\omega t - \phi)$

103. An applied voltage signal consists of a superposition of a DC voltage of high frequency. The circuit consists of an inductor and a capacitor in series. Show the DC signal will appear across C and the AC voltage across L.

Ans : **Main 2024**

Inductive reactance, $X_L = \omega L$

Capacitive reactance, $X_C = \dfrac{1}{\omega C}$

For DC in steady state $\omega = 0$; $X_L = 0$, $X_C = \infty$ (for DC).

Thus, the inductive reactance has zero value for DC and very high value for high frequency AC. On the other hand capacitance offers infinite reactance to DC and very low reactance to high frequency AC.

So, when inductor and capacitor are connected in series, the capacitor gives easy path to AC and does not allow DC while inductor gives easy path to DC and offers very high opposition to AC. Hence, DC signal will appear across C and AC voltage across L.

104. An inductor L or reactance X_L is connected in series with a bulb B to an AC source as shown in figure. Explain briefly how does the brightness of the bulb change when (1) number of turns of the inductor is reduced (2) a capacitor of reactance $X_C = X_L$ is included in the circuit.

Ans : **Comp 2017, 2015**

1. When the number of turns in the inductor is reduced, the self-inductance of the coil decrease; So, impedance of circuit reduces and current in the circuit $\left(I = \frac{E}{Z}\right)$ increases. Thus, the brightness of the bulb increases.
2. When capacitor of reactance $X_C = X_L$ is introduced, the net reactance of circuit becomes zero, so impedance of circuit decrease; it becomes $Z = R$; So current in circuit increases; hence brightness of bulb increases. Thus, brightness of bulb in both cases increases.

105. Radio-frequency choke is air cored, whereas audio frequency choke is iron cored. Explain.

Ans : **SQP 2018**

Radio Frequency Choke

The inductive reactance of choke is given by,

$$X_L = 2\pi\nu L$$

Radio frequency is very high frequency i.e. ν is large. So in order to keep X_L low, L should be low. This is possible only by using an air cored $(\mu = 1)$ inductance.

Audio Frequency Choke

In audio frequency choke, the frequency is low i.e. ν is small. So to have reasonable value of X_L, L should be high hence iron should be used for which the value of μ is high (because the value of L increases with μ).

106. Why an inductor is an easy path for DC and resistive path for AC?

Ans : **SQP 2009, 2001**

The inductor reactance (resistance offered by inductor) of an inductor is given by,

$$X_L = \omega L = 2\pi\nu L$$

where, ν is the frequency of AC source.

For DC

$$\nu = 0$$

Hence, $X_L = 2\pi 0 \cdot L = 0$

i.e. the inductor offers no resistance to DC.

For AC

ν is finite

Hence, $X_L \propto \nu$

So larger the value of ν, more will be the effective resistance offered by the inductor.

Hence an inductor is an easy path for DC but a resistive path for AC.

107. Obtain the relation for the current $I = I_0 \sin(\omega t - \pi/2)$ for a pure inductor across which an alternating emf $\varepsilon = \varepsilon_0 \sin \omega t$ is applied.

Ans : **Main 2007**

Consider the circuit containing inductor.

Let the emf $E = E_0 \sin \omega t$ is applied across a pure inductor L. Since, there is no resistance in the circuit, the net instantaneous emf is zero.

Applying KVL across the circuit, we hav e

$$E_0 \sin \omega t - L\frac{dI}{dt} = 0 \text{ or } dI = \frac{E_0}{L} \sin \omega t dt$$

Integrating, we have

$$\int dI = \frac{E_0}{L} \sin \omega t dt$$

NODIA

$$I = \frac{E_0}{L}\left(\frac{-\cos\omega t}{\omega}\right) = \frac{E_0}{\omega L}\sin\left(\omega t - \frac{\pi}{2}\right)$$

$$\left[-\cos\omega t = \sin\left(\omega t - \frac{\pi}{2}\right)\right]$$

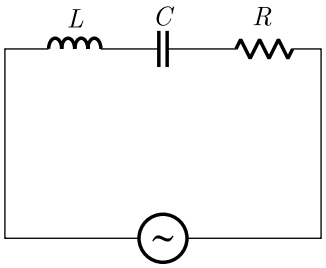
or $I = I_0 \sin(\omega t - \pi/2)$

where, $I_0 = \frac{E_0}{\omega L}$ is the maximum value of the current or peak current.

108. In a series L-C-R circuit Obtain an expression for resonant frequency.

Ans : **Main 2009**

For a series L-C-R circuit at resonance $X_C = X_L$, i.e. reactance of capacitor and inductor must be equal.



Now according to question

$$\omega_0 L = \frac{1}{\omega_0 C}$$

$$\omega_0^2 = \frac{1}{LC}$$

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

$$2\pi f_0 = \frac{1}{\sqrt{LC}}$$

Resonant frequency

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}$$

109. An alternating voltage of frequency f is applied across LCR circuit. Let f_r be the resonance frequency for the circuit. Will the current in the circuit lag, lead or remain in phase with the applied voltage when

1. $f > f_r$
2. $f < f_r$?

Explain your answer in each case.

Ans : **SQP 2017**

In an LCR circuit, the phase angle ϕ is given by,

$$\tan\phi = \frac{X_L - X_C}{R} = \frac{2\pi fL - \frac{1}{2\pi fC}}{R}$$

1. When $f > f_r$, then $X_L > X_C$ and the circuit is inductive dominant circuit and $\tan\phi$ is positive. So the current will lag behind the applied voltage by a phase ϕ.
2. When $f < f_r$, then $X_L < X_C$ and the circuit is capacitive dominant circuit, and $\tan\phi$ is negative, so the current will lead the applied voltage by a phase ϕ.

The current will remain in phase if $f = f_r$, then $X_L = X_C$ and the circuit is purely resistive and hence current and voltage are in phase.

110. Show that a capacitor is an easy path for AC but a block for DC (i.e. offers infinite resistance for DC).

Ans : **Comp 2007**

The capacitive eactance X_C (resistance offered by a capacitor) is given by,

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi\nu C}$$

where C is the capacitance of the capacitor and ν is the frequency of AC source.

For DC

$$\nu = 0$$

Hence, $X_C = \frac{1}{0} = \infty$

i.e. capacitor offers infinite resistance to DC in other words it blocks DC.

For AC, ν is finite

So, $X_C \propto \frac{1}{\nu}$

So larger the value of ν, smaller will be the value of X_C. Hence capacitor is an easy path for AC.

So a capacitor is an easy path for AC but a block for DC.

111. A resistance of $150\,\Omega$ and a capacitance of $15\,\mu F$ are connected in series with an AC source of 220 V. The peak value of the current is 0.20 A. Calculate the average power consumed in the circuit. If the capacitor is removed but the current is kept the same, what is the average power consumed in the resistor alone?

Ans : **Main 2007, 2004**

Initially,

$R = 150\,\Omega$

$C = 15\,\mu F$, peak current, $I_0 = 0.2\,A$

Impedance of circuit

$$Z = \frac{V_0}{I_0} = \frac{V_{rms} \times \sqrt{2}}{I_0}$$

$$= \frac{220 \times \sqrt{2}}{0.20} = \frac{220 \times 100}{20} \times \sqrt{2}$$

$$= 220 \times 5 \times \sqrt{2} = 1100\sqrt{2}\,\Omega$$

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Average power consumed

$$P_{av} = V_{rms} I_{rms} \cos\phi \qquad \left[\cos\phi = \frac{R}{Z}\right]$$

$$P_{av} = 220 \times \frac{0.2}{\sqrt{2}} \times \frac{150}{1100\sqrt{2}}$$

$$P_{av} = 3\ \text{W}$$

When there is only resistor in the circuit, power consumed is

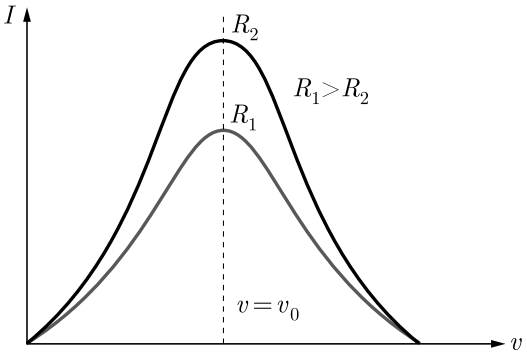
$$P_{av} = I_{rms}^2 R = \left(\frac{I_0}{\sqrt{2}}\right)^2 R$$

$$= \left(\frac{0.2}{\sqrt{2}}\right)^2 \times 150 = 3\ \text{W}$$

112. State the condition under which the phenomenon of resonance occurs in a series LCR circuit. Plot a graph showing the variation of current with frequency of an AC source in series LCR circuit.

Ans : **Main 2025**

The condition for series resonance is,



$$X_L = X_C$$

$$\omega_0 L = \frac{1}{\omega_0 C}$$

$$\omega_0^2 = \frac{1}{LC}$$

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

$$2\pi\nu_0 = \frac{1}{\sqrt{LC}}$$

(where ν_0 is resonance frequency)

$$\nu_0 = \frac{1}{2\pi\sqrt{LC}}$$

The graph between I and ν is as shown in figure.

113. An alternating voltage $V = V_m \sin\omega t$ applied to a series $L-C-R$ circuit drives a current given by $I = I_m \sin(\omega t + \phi)$. Deduce an expression for the average power dissipated over a cycle.

Ans : **SQP 2017**

Given, $V = V_m \sin\omega t$ and $i = i_m(\omega t + \phi)$

and instantaneous power, $P = Vi$

$$= V_m \sin\omega t \cdot i_0 \sin(\omega t + \phi)$$

$$= V_m i_m \sin\omega t \sin(\omega t + \phi)$$

$$= \frac{1}{2} V_m i_m 2 \sin\omega t \cdot \sin(\omega t + \phi)$$

From trigonometric formula,

$2\sin A \sin B = \cos(A - B) - \cos(A + B)$

Hence, instantaneous power,

$$P = \frac{1}{2} V_m i_m [\cos(\omega t + \phi - \omega t) - \cos(\omega t + \phi + \omega t)]$$

$$= \frac{1}{2} V_m i_m [\cos\phi - \cos(2\omega t + \phi)]$$

Average power for complete cycle

$$P_{av} = \frac{1}{2} V_m i_m [\cos\phi - \cos(2\omega t + \phi)] \quad ...(1)$$

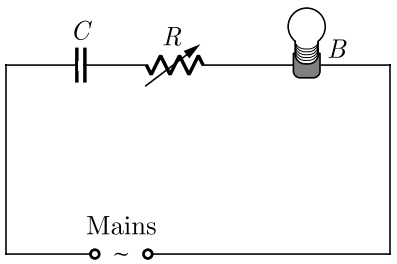
Where $\cos(2\omega t + \phi)$ is the mean value of $\cos(2\omega t + \phi)$ over complete cycle. But for a complete cycle, $\cos(2\omega t + \phi) = 0$

Since, Average power,

$$P_{av} = \frac{1}{2} V_m i_m \cos\phi = \frac{V_0}{\sqrt{2}} \frac{i_0}{\sqrt{2}} \cos\phi$$

$$P_{av} = V_{rms} i_{rms} \cos\phi$$

114. A capacitor C, a variable resistor R and a bulb B are connected in series to the AC mains in the circuit as shown. The bulb glows with some brightness. How will the glow of the bulb change if (i) a dielectric slab is introduced between the plates of the capacitor keeping resistance R to be the same (ii) the resistance R is increased keeping the same capacitance?



Ans : **SQP 2016**

(i) As, the dielectric slab is introduced between the plates of the capacitor, its capacitance will increase. Hence, the potential drop across the capacitor will decrease, i.e., $V = \frac{Q}{C}$. As a result, the potential drop across the bulb will increase as they are connected in series. Thus its brightness will increase.

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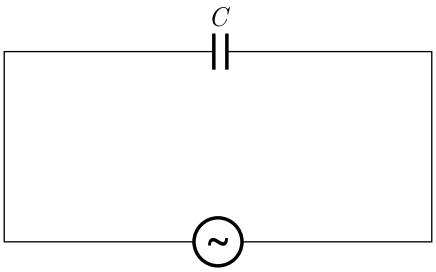
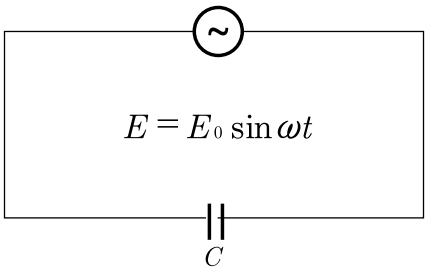


Ans : **Main 2003, 2019**

Let alternating voltage, $E = E_0 \sin \omega t$ is applied across a capacitor C. At any instant, the potential difference across the capacitor is equal to applied voltage.



$E =$ Potential difference across the capacitor $= \frac{q}{C}$

But $E = E_0 \sin \omega t$ ...(1)

$$E_0 \sin \omega t = \frac{q}{C} \Rightarrow q = E_0 C \sin \omega t$$

$$\frac{dq}{dt} = \omega C E_0 \cos \omega t$$

$$I = \frac{E_0}{1/\omega C} \cos \omega t$$

$$I = I_0 \sin\left(\omega t + \frac{\pi}{2}\right) \quad ...(2)$$

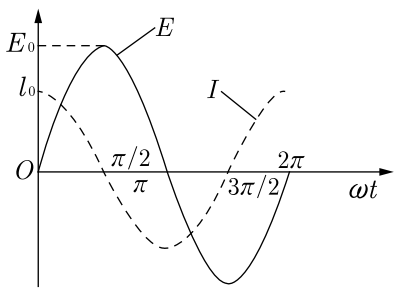
Where, $I_0 = \frac{E_0}{\left(\frac{1}{\omega C}\right)} = \frac{E_0}{X_C}$

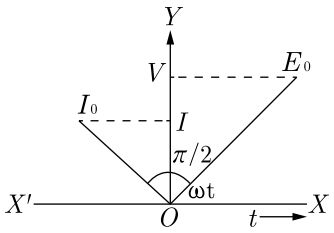
Capacitive reactance,

$$X_C = \frac{1}{\omega C}$$

From Eqs. (1) and (2), current leads the voltage by phase $\pi/2$.

The graph between E and I versus ωt phaser diagram as shown below.





Phasor diagram

FOUR MARKS QUESTIONS

125. A voltage $V = V_0 \sin \omega t$ is applied to a series $L - C - R$ circuit. Derive the expression for the average power dissipated over a cycle.Under what condition is (i) no power dissipated even though the current flows through the circuit. (ii) maximum power dissipated in the circuit? Show that power dissipated at resonance is maximum.

Ans : **Main 2004**

Instantaneous power dissipation in the circuit.

$$P = VI = V_0 \sin \omega t \times I_0 \sin(\omega t - \phi)$$

$$= \frac{V_0 I_0}{2} \times 2 \sin \omega t \cdot \sin(\omega t - \phi)$$

$$= \frac{V_0 I_0}{2} [\cos \phi - \cos(2\omega t - \phi)]$$

$$[\cos(A - B) - \cos(A + B) = 2 \sin A \sin B]$$

Average power loss over one complete cycle.

$$P = \frac{1}{T} \int_0^T P dt$$

$$= \frac{V_0 I_0}{2T} \left[\int_0^T \cos \phi \, dt - \int_0^T \cos(2\omega t - \phi) \, dt \right]$$

However,

$$\int_0^T \cos(2\omega t - \phi) \, dt = 0$$

$$= \frac{V_0 I_0}{2T} \cdot \cos \phi \int_0^T dt$$

$$= \frac{V_0 I_0}{2} \cos \phi$$

$$P_{av} = \frac{V_0}{\sqrt{2}} \frac{I_0}{\sqrt{2}} \cos \phi$$

$$P_{av} = V_{eff} \cdot I_{eff} \cos \phi$$

(i) If phase angle $\phi = 90^\circ$ (resistance R is used in the circuit) then no power dissipated.

(ii) If phase angle $\phi = 0^\circ$ or circuit is pure resistive (or $X_L = X_C$) at resonance then,

Max power, $P = V_{eff} \times I_{eff} = \frac{V_0 I_0}{2}$

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(ii) If $\phi = 0^\circ$, then maximum power is dissipated in the circuit.

$$P_{av} = \text{maximum}$$

$$\tan\phi = \frac{\omega L - \frac{1}{\omega C}}{R} = 0$$

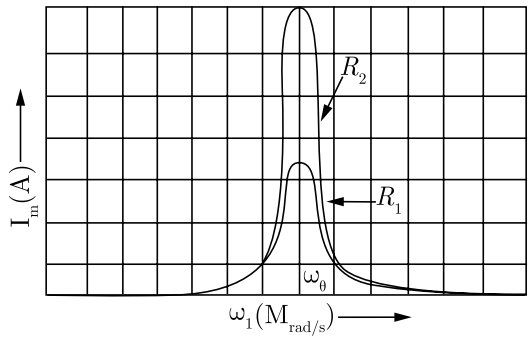
(Since, $\tan 0^\circ = 0$)

$$X_L = X_C$$

118. In a series LCR circuit connected to an AC source of variable frequency and voltage $V = V_m \sin\omega t$, draw a graph showing the variation of current (i) with angular frequency (ω) for two different values of resistance R_1 and $R_2 (R_1 > R_2)$. Write the condition under which the phenomenon of resonance occurs. For which value of the resistance out of the two curves, a sharper resonance is produced? Define Q-factor of the circuit and give its significance.

Ans : SQP 2018, 2007

Figure shows the variation of i_m with ω in a LCR series circuit for two values of resistance R_1 and $R_2 (R_1 > R_2)$.



The condition for resonance in the LCR circuit is

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

We see that the current amplitude is maximum at the resonant frequency ω. Since $i_m = \frac{V_m}{R}$ at resonance, the current amplitude for case R_2 is sharper to that for case R_1.

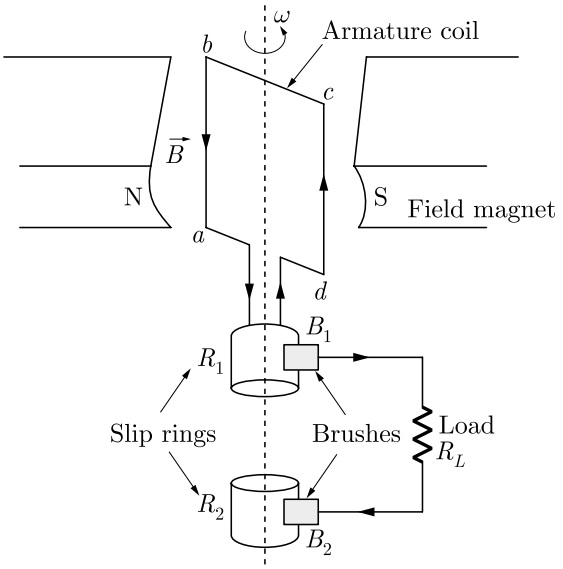
Quality factor or simply the Q-factor of a resonant LCR circuit is defined as the ratio of voltage drop across the capacitor (or inductor) to that of applied voltage.

It is given by $$Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$

The Q-factor determines the sharpness of the resonance curves. Less sharp the resonance, less is the selectivity of the circuit while higher is the Q, sharper is the resonance curve and lesser will be the loss in energy of the circuit.

119. Draw a labelled diagram of an AC generator. Obtain the expression for the emf induced in the rotation coil of N turns each of cross sectional area A, in the presence of a magnetic field B.

Ans : SQP 2016, 2012



An AC generator converts mechanical energy into electric energy. It consists of a coil mounted on a rotor shaft. The axis of rotation of coil is perpendicular to magnetic field and the coil (armature) is mechanically rotated in magnetic field. Rotation causes magnetic flux. Hence an emf is induced in coil.

Let ω be angular velocity and θ be the angle between magnetic field and area vector, then $\theta = \omega t$, hence flux is

$$\phi_B = BA\cos\theta$$

$$= -NBA\frac{d}{dt}(\cos\omega t)$$

Thus, instantaneous emf is,

$$\varepsilon = NBA\omega\sin\omega t$$

If $NAB\omega = \varepsilon_0$

then, $$\varepsilon = \varepsilon_0 \sin\omega t$$

Since, function varies between ± 1 and emf for $\theta = 0^\circ$ to $\theta = 270^\circ$.

The direction of current change periodically, hence called alternating current.

120. A series $L - C - R$ circuit is connected to an AC source. Using the phaser diagram. Derive the expression for the impedance of the circuit. Plot a graph to show the variation of current with frequency of the source, explaining the nature of its variation.

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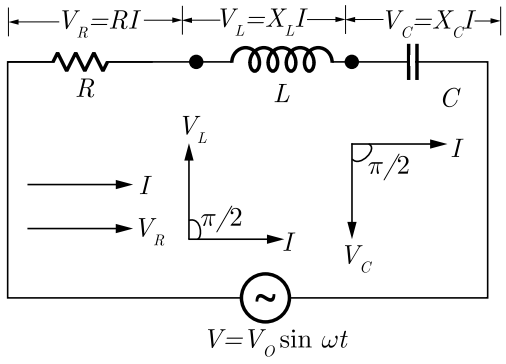
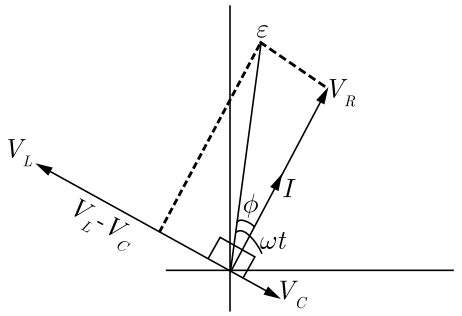
Ans : **Main 2017**

Assuming $X_L > X_C$, $V_L > V_C$

Since, Net voltage, $V = \sqrt{V_R^2 + (V_L - V_C)^2}$

Where, V_L, V_C and V_R are alternating voltages across L ,C and R respectively.





$$V_R = IR,\ V_L = IX_L,$$

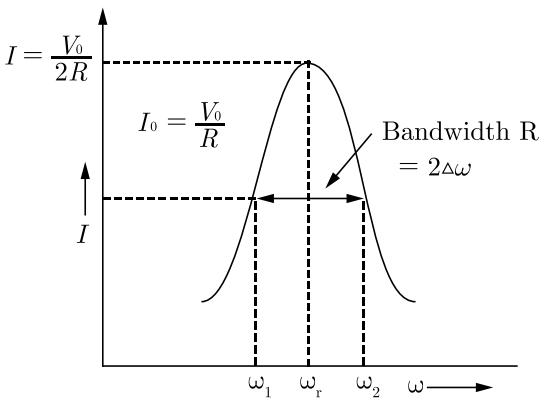
$$V_C = IX_C$$

Net voltage, $$V = \sqrt{(IR)^2 + (IX_L - IX_C)^2}$$

$$\frac{V}{I} = \sqrt{R^2 + (X_L - X_C)^2}$$

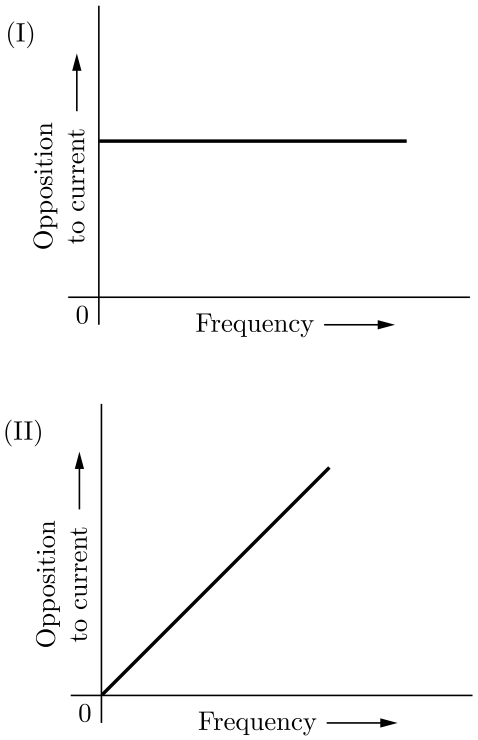
Impedance of LCR circuit,

$$Z = \frac{V}{I} = \sqrt{R^2 + (X_L - X_C)^2}$$



121. (i) The graphs (i) and (ii) represents the variation of the opposition offered by the circuit element to the flow of alternating current with frequency of the applied emf. Identify the circuit element corresponding to each graph.

(ii) Write the expression for the impedance offered by the series combination of the above two elements connected across the AC sources. Which will be ahead in phase in this circuit, voltage or current?



Ans : **SQP 2008**

(i) From graph (i), it is clear that resistance (opposition to current) is not changing with frequency, i.e., resistance does not depend on frequency of applied source, so the circuit element here is pure resistance (R).

(ii) From graph (ii), it is clear that resistance increase linearly with frequency, so the circuit element here is an inductor.

Inductive resistance, $X_L = 2\pi fL$

$$X_L \propto f$$

(i) Impedance offered by the series combination of resistance R and inductor L.

$$Z = \sqrt{R^2 + X_L^2}$$

$$= \sqrt{R^2 + (2\pi fL)^2}$$

In LR circuit, the applied voltage leads the current in phase by $\frac{\pi}{2}$.

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122. A series LCR circuit derives a current given by $I = I_m \sin(\omega t + \phi)$. Deduce an expression for the average power dissipated over a cycle.

Ans : **SQP 2011, 2015**

Let at any instant, the current and voltage in an LCR series AC circuit is given by

$$I = I_0 \sin \omega t$$

$$V = V_0 \sin(\omega t + \phi)$$

The instantaneous power is given by

$$P = VI = V_0 \sin(\omega t + \phi)\, I_0 \sin \omega t$$

$$P = \frac{V_0 I_0}{2}[2 \sin \omega t \sin(\omega t + \phi)]$$

$$P = VI$$

$$= \frac{V_0 I_0}{2}[\cos \phi - \cos(2\omega t + \phi)] \quad ...(1)$$

[Since, $2 \sin A \sin B = \cos(A - B) - \cos(A + B)$]

Work done for a very small time interval dt is given by

$$dW = Pdt$$

$$dW = VIdt$$

Hence, Total work done over T, a complete cycle is given by

$$W = \int_0^T VIdt$$

But, $$P_{av} = \frac{W}{T} = \frac{\int_0^T VIdt}{T}$$

$$P_{av} = \frac{1}{T}\int_0^T VIdt$$

$$= \frac{1}{T}\int_0^T \frac{V_0 I_0}{2}[\cos \phi - \cos(2\omega + \phi)]\, dt$$

or $$P_{av} = \frac{V_0 I_0}{2T}\left[\int_0^T \cos \phi\, dt - \int_0^T \cos(2\omega t + \phi)\, dt\right]$$

$$= \frac{V_0 I_0}{2T}[\cos \phi (t)_0^T - 0]$$

(By trigonometry)

$$P_{av} = \frac{V_0 I_0}{2T} \times \cos \phi \times T$$

$$= \frac{V_0 I_0}{2} \times \cos \phi$$

$$P_{av} = \frac{V_0}{\sqrt{2}} \times \frac{I_0}{\sqrt{2}} \cos \phi$$

$$P_{av} = V_{rms} \times I_{rms} \times \cos \phi$$

This is the required expression.

123. Show that the current leads the voltage in phase by $\frac{\pi}{2}$ in an AC circuit containing an ideal capacitor.

Ans : **Main 2014**

Let us consider a capacitor C connected to an AC source as shown below

Let the AC voltage applied be,

$$V = V_m \sin \omega t \quad ...(1)$$

Hence, $$V = \frac{q}{C} \quad ...(2)$$

From eqs. (1) and (2), we have

$$V_m \sin \omega t = \frac{q}{C}$$

$$q = CV_m \sin \omega t$$

Also, $$i = \frac{dq}{dt}$$

$$i = \frac{d}{dt}(CV_m \sin \omega t)$$

$$i = \omega C V_m \cos \omega t \quad ...(3)$$

$$\cos \omega t = \sin\left(\omega t + \frac{\pi}{2}\right) \quad ...(4)$$

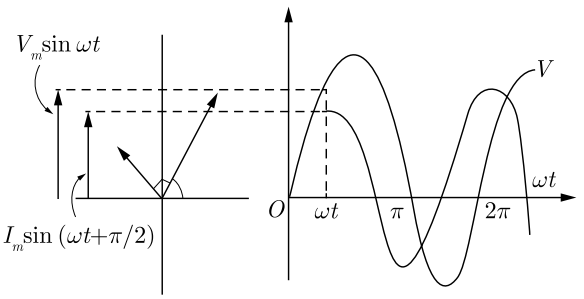
in the circuit, $$V_m = i_m X_c = i_m \frac{I}{\omega C}$$

$$i_m = V_m \omega C \quad ...(5)$$

Substituting the value of eqs. (4) and (5) in eq. (3), we get,

$$i = i_m \sin\left(\omega t + \frac{\pi}{2}\right)$$

The phase diagram which shows the current lead the voltage in phase by 90° is given below :



124. Obtain the relation $I = I_0 \sin(\omega t + \pi/2)$ and $X_L = 1/\omega C$ for a pure capacitor across which an AC emf of $\varepsilon = \varepsilon_0 \sin \omega t$ is applied as shown in the figure. Draw a phaser diagram showing emf ε, current I and their phase difference ϕ.

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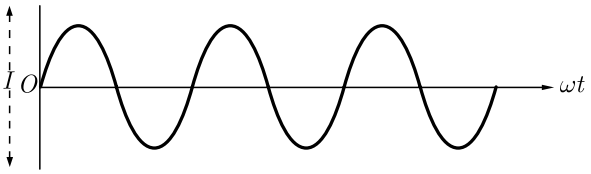
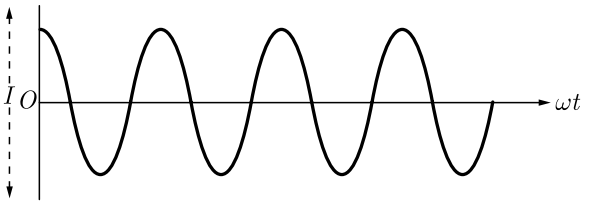


(a)



(b)

where, I_0 is the peak value of AC.

Similarly, the e.m.f. whose magnitude changes with time and direction reverses periodically is called alternating e.m.f.

The instantaneous alternating e.m.f. is given by,

$$E = E_0 \sin \omega t \quad ...(3)$$

or $$E = E_0 \cos \omega t \quad ...(4)$$

where, $\omega = \frac{2\pi}{T}$ is angular frequency.

Time Period (T) : Time period is the time taken to complete one cycle.

Frequency (ν) : Frequency is the number of cycles per second. So frequency,

$$\nu = \frac{1}{T}$$

Since, $$T = \frac{2\pi}{\omega}$$

Hence, $$\nu = \frac{\omega}{2\pi}$$

$$\omega = 2\pi\nu$$

Amplitude (I_0) : Amplitude of alternating current is the peak value of alternating current and is denoted by I_0.

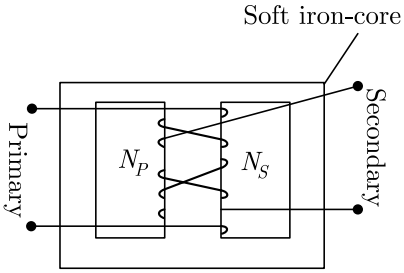
128. Show diagrammatically two different arrangements used for winding the primary and secondary coils in a transformer. Assuming the transformer to be an ideal one, write the expression for the ration of its:

1. Output voltage to input voltage.
2. Output current to input current.

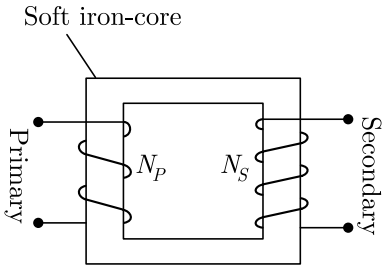
Mention two reasons for energy losses in an actual transformer.

Ans : **Main 2025, 2015**

Arrangement of winding of primary and secondary coil in a transformer are shown in fig (a) and (b).



(a) Two coils on to of each other



(b) Two coils on separate limbs of the core

1. Ratio of output voltage to input voltage,

$$\frac{V_s}{V_p} = \frac{N_s}{N_P}$$

2. Ratio of output current to input current,

$$\frac{I_s}{I_p} = \frac{N_p}{N_s}$$

Reasons for energy losses in a transformer

1. **Joule Heating :** Energy is lost due to heating of primary and secondary windings as heat (I^2Rt).
2. **Flux Leakage :** Energy is lost due to coupling of primary and secondary coils not being perfect, i.e., whole of magnetic flux generated in primary coil is not linked with the secondary coil.

129. What is a choke coil? Discuss its use in AC circuits?

Ans : **SQP 2021**

A choke coil is simply an inductor with large value of self-inductance.

The choke coil consists of a large number of turns of thick copper wire bound closely over a laminated soft iron core. The inductive reactance offered by the coil is $X_L = \omega L$ becomes large. Therefore, magnitude of AC is reduced.

In an ideal choke coil, ohmic resistance $= 0$. Therefore, no electrical energy/power is wasted.

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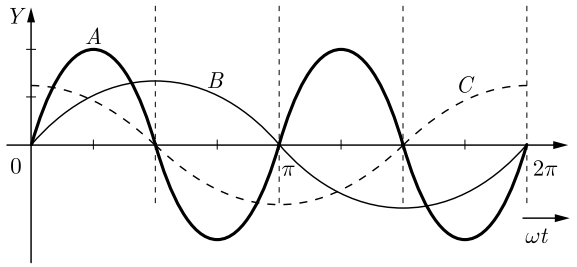
At resonance, we get

$$X_C = X_L$$
$$\tan\phi = 0$$
$$\phi = 0^\circ$$
$$\cos\phi = 1, \text{ its maximum value.}$$

Hence, P has its maximum value at resonance

126. A device X is connected to an AC source $V = V_0 \sin \omega t$. The variation of voltage, current and power in one cycle is shown in the following graph:



(a) Identify the device X.

(b) Which of the curves A, B and C represent the voltage, current and the power consumed in the circuit ? Justify your answer.

(c) How does its impedance vary with frequency of the AC source? Show graphically.

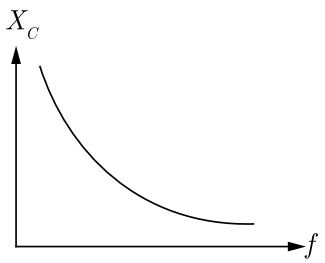
(d) obtain an expression for the current in the circuit and its phase relation with AC voltage.

Ans : **Comp 2017**

(a) Device is capacitor.

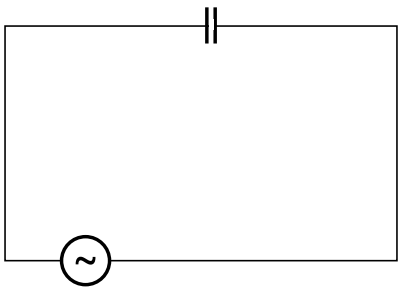
(b) $B \rightarrow$ Voltage (Because it is sine wave)
$C \rightarrow$ Current (Because current leads voltage by $\frac{\pi}{2}$
$A \rightarrow$ Power (Average power over one cycle is zero)

(c) $$X_C = \frac{1}{\omega_C}$$



$$X_C = \frac{1}{2\pi f_C}$$

(d) $$V = V_0 \sin \omega t$$



$$C = \frac{q}{v}$$
$$q = cv_0 \sin \omega t$$
$$i = \frac{dq}{dt} = \frac{d}{dt}(cv_0 \sin wt)$$
$$= \omega c v_0 \sin \omega t$$
$$= \frac{v_0}{\frac{1}{\omega_C}} \cos \omega t$$
$$i = \frac{v_0}{X_C} \sin\left(\omega t + \frac{\pi}{2}\right)$$
$$i = i_0 \sin\left(\omega t + \frac{\pi}{2}\right)$$

In pure capacitive circuit leads voltage by $\frac{\pi}{2}$

127. What is alternating current? How alternating e.m.f. and current is represented mathematically. What do you mean by time period, frequency and amplitude of alternating current?

Ans : **Comp 2021, 2018**

The current in which both the magnitude and direction undergo a complete cycle of changes periodically is called alternating current. It increases from zero to a maximum value, then decreases to zero and reverses in direction. It once again becomes maximum in this direction and then reduced to zero. This complete set of variations in magnitude and direction of current or e.m.f. is called a cycle. During one cycle, the current flows in one direction, of course, changing in magnitude in the first half cycle and in the opposite direction during the next half cycle.

Thus current whose magnitude changes with time and direction reverses periodically is called alternating current.

The instantaneous value of AC is given by,

$$I = I_0 \sin \omega t \text{ [Figure (a)]} \quad ...(1)$$

or $$I = I_0 \cos \omega t \text{ [Figure (b)]} \quad ...(2)$$

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(ii) As the resistance R is increased, the potential drop across the resistor will increase. As a result, the potential drop across the bulb will decrease as they are connected in series. Thus, its brightness will decrease.

115. In a series $L-C-R$ circuit, obtain the conditions under which (i) the impedance of circuit is minimum and (ii) watt-less current flows in the circuit.

Ans : **Main 2013, 2009**

(i) The impedance of a series $L-C-R$ circuit is given by

$$Z=\sqrt{R^2+\left(\omega L-\frac{1}{\omega C}\right)^2}$$

Z will be minimum when $\omega L=\frac{I}{\omega C}$, i.e., When the circuit is under resonance.

Hence, for this condition Z will be minimum and equal to R.

(ii) Average power dissipated through a series $L-C-R$ circuit is given by

$$P_{av} = E_v I_v \cos\phi$$

Where, EV = rms value of alternating voltage

I_V = value of alternating current

ϕ = phase difference between current and voltage

For wattless current, the power dissipated through the circuit should be zero.

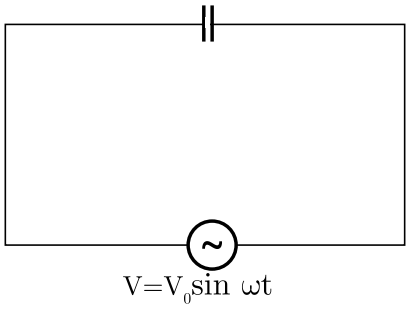
i.e., $\cos\phi = 0$

$$\cos\phi = \cos\frac{\pi}{2}$$

$$\phi = \frac{\pi}{2}$$

Hence, the condition for wattless current is that the phase difference between the current and the circuit is purely inductive or purely capacitive.

116. Show that the current leads the voltage in phase by $\frac{\pi}{2}$ in an AC circuit containing an ideal capacitor.



Ans : **SQP 2012**

The instantaneous voltage,

$$V = V_0\sin\omega t \quad ...(1)$$

Let q be the charge on capacitor and I, the current in the circuit at any instant, then instantaneous potential difference,

$$V=\frac{q}{c} \quad ...(2)$$

From eqs. (1) and (2), we get

$$\frac{q}{c} = V_0\sin\omega t$$

$$q = CV_0\sin\omega t$$

The instantaneous current,

$$I=\frac{dq}{dt} = \frac{d}{dt}(CV_0\sin\omega t)$$

$$= CV_0\frac{d}{dt}(\sin\omega t)$$

$$= CV_0\omega\cos\omega t$$

$$I=\frac{V_0}{\frac{1}{\omega C}}\cos\omega t$$

$$I = I_0\sin\left(\omega t+\frac{\pi}{2}\right)$$

Hence, the current leads the applied voltage in phase by $\frac{\pi}{2}$.

117. A voltage $V = V_0\sin\omega t$ is applied to a series LCR circuit. Derive the expression for the average power dissipated over a cycle.

Under what condition is (i) no power dissipated even though the current flows through the circuit (ii) maximum power dissipated in the circuit?

Ans : **Comp 2015**

Let applied alternating voltage,

$$V = V_0\sin\omega t \quad ...(1)$$

, $$I = I_0\sin(\omega t-\phi) \quad (2)$$

Power, $P = VI$

Substituting the value of V and I from eq. (1) and eq. (2), we get

$$P = V_0\sin\omega t\cdot I_0\sin(\omega t-\phi)$$

So, the instantaneous power is given by

$$\sin(\omega t-\phi)=\sin\omega t\cos\phi-\cos\omega t\sin\phi$$

(i) If $\phi = 90^\circ$, then no power is dissipated even though the current flows through the circuit.

$$P_{av}=0$$

$$\tan\phi=\left(\frac{X_L-X_C}{R}\right)$$

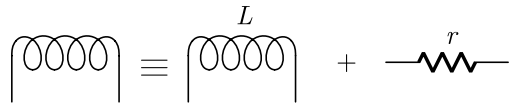
$$\tan\phi=\frac{\omega L-\frac{1}{\omega C}}{R}=\infty$$

(Since, $\tan 90^\circ = \infty$)

A phase angle of $\frac{\pi}{2}$ is introduced between current and voltage through an ideal inductor.

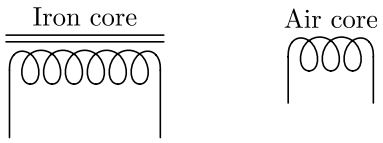
Hence, average power over a complete cycle is,

$$P = E_v I_v \cos\phi = E_v I_v \cos 90^\circ = 0$$



However, in actual practice, a choke coil of inductance L is linked with a small resistance r . It may be treated as a series combination of L and r. As shown in the figure. Therefore, average power consumed over a complete cycle in the practical choke coil is

$$P = E_v I_v \cos\phi = E_v I_v \frac{r}{\sqrt{r^2 + \omega^2 L^2}}$$



(a) (b)

In practice, a low frequency choke is made of insulated copper wire wound over a soft iron core [laminated] called low frequency choke or audio frequency choke figure (a) and a high frequency choke has air as core material figure (b) to eliminate eddy current losses. High frequency chokes are also called radio-frequency chokes.

Air is used as core material because, the virtual value of AC is given by,

$$I_v = \frac{E_v}{\omega L} = \frac{E_v}{2\pi\nu L}$$

So as ν is very high, so L should not be large, hence air cored choke is used.

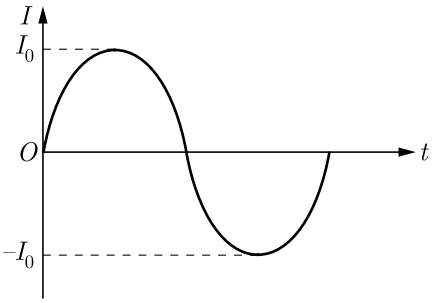
130. Define alternating current (AC), its peak value and its R.M.S. value. Derive relation between then after evaluating the expression for R.M.S. value.

Ans : **Main 2020**

If the direction of current changes alternatively (periodically) and its magnitude changes continuously with respect to time, then the current is called alternating current. It is sinusoidal (i.e. represented by sine or cosine angles) in nature. Alternating current can be defined as the current whose magnitude and direction changes with time and attains the same magnitude and direction after a definite time interval It changes continuously between zero and a maximum value and flows in one direction in the first half cycle and in the opposite direction in the next half cycle.

The instantaneous value of AC is given by,

$$I = I_0 \sin\omega t \qquad \left[\text{Since, } \omega = \frac{2\pi}{T} = 2\pi v\right]$$



Current vs time graph of an AC

Where, I = current at any instant t

I_0 = maximum/peak value of AC

v = frequency

and ω = angular frequency

Roof Mean Square (RMS) Value of AC

It is defined as that value of alternating current (AC) over a complete cycle which would generator same amount of heat in a given resistor that is generated by steady current in the same resistor and in the same time during a complete cycle.

It is also called virtual value or effective value of AC.

It is represented by I_{rms} or I_{eff} or I_V. Suppose I is the current which flows in the resistor having resistance R in time T produces heat H.

Instantaneous value of AC,

$$I = I_0 \sin\omega t$$

If dH is small amount of heat produced in time dt in resistor R, then

$$dH = I^2 R dt \qquad [\text{Since, } H = I^2 RT] \ldots(1)$$

In complete cycle $(0 \to T)$, the total heat produced is H.

After integrating Eq. (1), we get

$$\int dH = \int_0^T I^2 R dt$$

$$H = \int_0^T I^2 R dt$$

Put the value of I in the above equation, we get

$$H = \int_0^T (I_0 \sin\omega t)^2 R\, dt$$

$$= I_0^2 R \int_0^T \sin^2\omega t\, dt$$

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137. The power factor of an AC circuit is 0.5. What is the phase difference between voltage and current in the circuit?

Ans : SQP 2017

$$\cos\theta = 0.5$$
$$\cos\theta = \cos 60^\circ$$
$$\theta = 60^\circ$$
$$\text{Phase angle} = 60^\circ$$

138. An AC generator generates an emf ε given by $\varepsilon = 311\sin(100\pi t)$ volt. Then, find the rms value of the emf generated by the generator.

Ans : Main 2009

Given, $\varepsilon = 311\sin(100\pi t)$ volt

On comparing with $\varepsilon = \varepsilon_0 \sin\omega t$

Peak emf, $e_0 = 311\text{ V}$

So, $e_{\text{rms}} = \dfrac{e_0}{\sqrt{2}} = \dfrac{311}{\sqrt{2}} = 219.9\text{ V} \approx 220\text{ V}$

139. A light bulb is rated 100 W for 220 V AC supply of 50 Hz. Calculate:

1. The resistance of the bulb.
2. The r.m.s. current through the bulb.

Ans : Main 2010, 2007

1. $R = \dfrac{V_{rms}^2}{P} = \dfrac{220\times 220}{100} = 484\,\Omega$

2. $I_{rms} = \dfrac{P}{V_{rms}} = \dfrac{100}{220} = 0.45\text{ A}$

140. A $30\,\mu$F capacitor, 0.2 H inductor and a $50\,\Omega$ resistor are connected in series to an AC source whose emf is given by $E = 310\sin(314t)$, where E is in volt and t is in second. Calculate

(i) the impedance of the circuit.

(ii) peak value of current in the circuit.

Ans : Main 2025

This is a similar question as that of the previous one hence, follow the similar method to calculate impedance and peak current.

(i) $Z = 66.2\,\Omega$

(ii) $I_0 = 4.68\text{ A}$

141. When an alternating emf $e = 300\sin(100\pi t + \pi/6)$ volt is applied to a circuit, the current I through it is $I = 5.0\sin(100\pi t - \pi/6)$ ampere. Then, find the phase difference between the emf and current.

Ans : Main 2009

Given $e = 300\sin(100\pi t - \pi/6)\text{ V}$ ...(1)

and $I = 5\sin(100\pi t - \pi/6)\text{ A}$ ...(2)

Comparing Eqs. (1) and (2) with standard equation, the phase difference between emf (e) and current (I) is

$$\Delta\phi = \phi_1 - \phi_2$$
$$= \frac{\pi}{6} - \left(-\frac{\pi}{6}\right) = \frac{\pi}{3}\text{rad} = 60^\circ$$

142. A 60 W load is connected to the secondary of a transformer whose primary draws line voltage. If a current of 0.54 A flows in the load, what is the current in the primary coil? Comment on the type of transformer being used.

Ans : SQP 2013

Given: $P_L = 60\text{ W}$

$I_L = 0.54\text{ A}$

$V_L = \dfrac{P_L}{I_L} = \dfrac{60}{0.54} = 111.11 \approx \text{V}$

The transformer is step and have $\frac{1}{2}$ input voltage.

Hence, $i_p = \dfrac{1}{2}\times I_L$

$= \dfrac{1}{2}\times 0.54 = 0.27\text{ A}$

143. A light bulb is rated 150 W for 220 V AC supply of 60 Hz. Calculate:

1. The resistance of the bulb.
2. The rms current through the bulb.

Ans : Main 2008

1. $P = 150\text{ W}$ and $\text{V} = 220\text{ Volt}$

Resistance of the bulb,

$$R = \frac{V^2}{P} = \frac{220\times 220}{150} = 322.7\,\Omega$$

2. As, $I_{rms} = \dfrac{V_{rms}}{R}$

$= \dfrac{220}{322.7}$ $(V_{\text{rms}} = V = 220\text{ Volt})$

$= 0.68\text{ A}$

144. In an AC circuit, $R = 4\,\Omega$, $Z = 5\,\Omega$, $V_{\text{rms}} = 200\text{ V}$ and $I_{\text{rms}} = 1.5\text{ A}$. Calculate the average power consumed over a full cycle.

Ans : Main 2003

Given,

$R = 4\,\Omega$, $V_{\text{rms}} = 200\text{ Volt}$,

$Z = 5\,\Omega$, $I_{\text{rms}} = 1.5\text{ A}$

As, we know power of an AC circuit is given by

$$P_{\text{av}} = V_{\text{rms}} I_{\text{rms}} \cos\phi$$

(where, $\cos\phi =$ power factor $= \dfrac{R}{Z}$)

$$P = 200\times 1.5\times\frac{4}{5} = 240\text{ W}$$

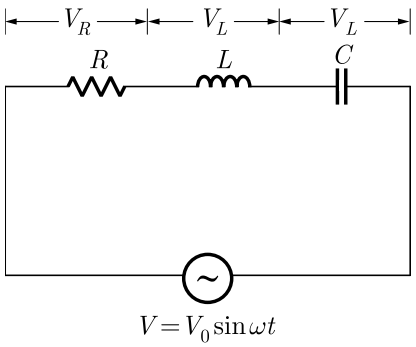
NODIA

In step-up transformer, $N_s > N_p \rightarrow r > 1$; So $V_s > V_p$ and $i_s < i_p$
i.e., Step up transformer increases the voltage.
In step down transformer, $N_s < N_p \rightarrow r < 1$; So $V_s < V_p$ and $i_s > i_p$
i.e., Step-up down transformer decreases the voltage, but increase the current.
The core of a transformer is laminated to reduce the energy losses due to eddy currents, so, that its efficiency may remain nearly 100%.
In a transformer with 100% efficiency (say), input power = output power $dV_pI_p = V_sI_s$.

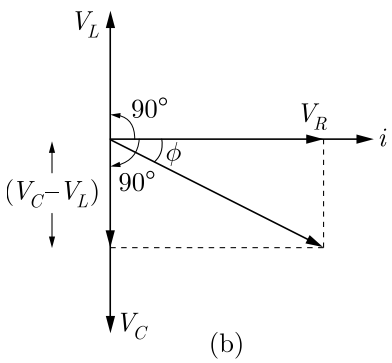
132. An AC source of voltage $V = V_0 \sin \omega t$ is connected to a series combination of L, C and R. Use the phasor diagram to obtain expression for impedance of the circuit and phase angle between voltage and current. Find the condition when current will be in phase with the voltage. What is the circuit in this condition called?

Ans : **SQP 2020, 2017**

Expression for impedance in LCR series circuit. Suppose resistance R, inductance L and capacitance C are connected in series and an alternating source of voltage $V = V_0 \sin \omega t$ is applied across it. [Figure (a)] On account of being in series, the current (i) flowing through all of them is the same.



(a)



(b)

Suppose, the voltage across resistance R is V_R, voltage across inductance L is V_L and voltage across capacitance C is V_C. The voltage V_R and current i are in the same phase, the voltage V_L will lead the current by angle 90° while the voltage V_C will lag behind the current by angle 90° [Figure (b)] clearly, V_C and V_L are in opposite directions, therefore their resultant potential difference $= V_C - V_L$ (if $V_C > V_L$).

Thus, V_R and $(V_C - V_L)$ are mutually perpendicular and the phase difference between them is 90°. As applied voltage across the circuit is V, the resultant of V_R and $(V_C - V_L)$ will also be V. From figure.

$$V^2 \; V_R^2 + (V_C - V_L)^2$$

$$V = \sqrt{V_R^2 + (V_C - V_L)^2} \qquad ...(1)$$

But, $V_R = iR$, $V_C = X_C \; i$

and $V_L = X_L i$

Where, $X_C = \frac{1}{\omega C} =$ capacitance reactance and $X_L = \omega L =$ inductive reactance.

Hence, $V = \sqrt{(iR)^2 + (iX_C - iX_L)^2}$

Hence, impedances of circuit,

$$Z = \frac{V}{i} = \sqrt{R^2 + (X_C - X_L)^2}$$

i.e., $$Z = \sqrt{R^2 + (X_C - X_L)^2}$$

$$= \sqrt{R^2 + \left(\frac{1}{\omega C} - \omega L\right)^2}$$

Instantaneous current,

$$I = \frac{V_0 \sin (wt + \phi)}{\sqrt{R^2 + (\frac{1}{\omega C} - \omega L)^2}}$$

Phase difference (ϕ) in series LCR circuit is given by-

$$\tan \phi = \frac{V_C - V_L}{V_R}$$

$$= \frac{i_m (X_C - X_L)}{I_m R} = \frac{(X_C - X_L)}{R}$$

When current and voltage are in phase

$$\phi = 0 \Rightarrow X_C - X_L$$

$$= 0 \Rightarrow X_C = X_L$$

This condition is called resonance and the circuit is called resonant circuit.

133. State the working of AC generator with the help of a labelled diagram.

The coil of an AC generator having N turns, each of area A, is rotated with a constant angular velocity ω Deduce the expression for the alternating emf generated in the coil.

What is the source of energy generation in this device?

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Ans : **Comp 2024, 2015**

AC Generator : A dynamo or generator is a device which converts mechanical energy into electrical energy.

Principle It works on the principle of electromagnetic induction. When a coil rotates continuously in a magnetic field, the effective area of the coil linked normally with the magnetic field lines, changes continuously with time. This variation of magnetic flux with time results in the production of an alternating emf in the coil.

Construction : It consists of the four main parts.

1. **Field Magnet :** It produces the magnetic field. In the case of a low power dynamo, the magnetic field is generated by a permanent magnet, while in the case of large power dynamo, the magnetic filed is produced by an electromagnet.
2. **Armature :** It Consists of a large number of turns of insulated wire in the soft iron drum or ring. It can revolve an axle between the two poles of the field magnet. The drum or ring serves the two purposes: (i) It serves as a support to coils and (ii) It increases the magnetic filed due to air core being replaced by an iron core.
3. **Slip Rings :** The slip rings R_1 and R_2 are the two metal rings to which the ends of armature coil are connected. These rings are fixed to the shaft which rotates the armature coil so that the rings also rotate along with the armature.
4. **Brushes :** There are two flexible metal plates or carbon rods (B_1 and B_2) which are fixed and constantly touch the revolving rings. The output current in external load R_L is taken through these brushes.

   Working : When the armature coil is rotated in the strong magnetic field, the magnetic flux linked with the coil changes and the current is induced in the coil, its direction being given by Fleming's right hand rule. Considering the armature to be in vertical position and as it rotates in anticlockwise direction, the wire ab moves upward and cd downward, so that the direction of induced current is shown in fig. In the external circuit, the current is shown in fig. In the external circuit, the current flows along $B_1R_LB_2$. The direction of current remains unchanged during the first half turn of armature. During the second half revolution, the wire ab moves downward and cd upward, so the direction of current is reversed and in external circuit it flows along $B_2R_LB_1$. Thus the direction of induced emf and current changes in the external circuit after each half revolution.

Expression for Induced emf

If N is number of turns in coil, f the frequency of rotation, A area of coil and B the magnetic induction, then induced emf.

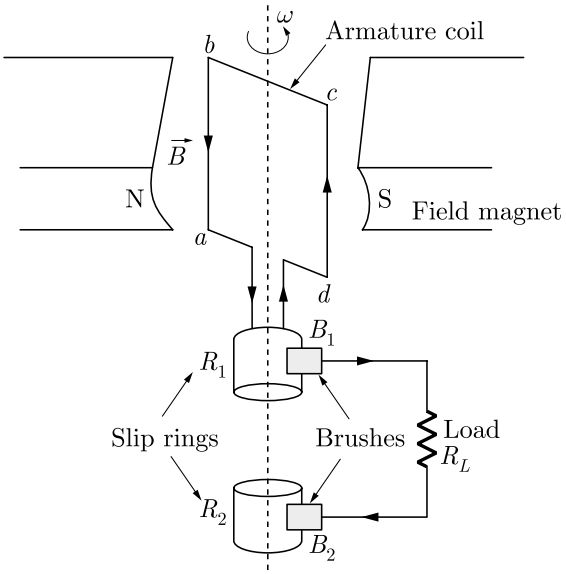
$$e = -\frac{d\phi}{dt} = -\frac{d}{dt}\{NBA(\cos 2\pi ft)\}$$

$$= 2\pi NBA\, f \sin 2\pi\, ft$$

Obviously, the emf produced is alternating and hence the current is also alternating.

Current produced by an AC generator cannot be measured by moving coil ammeter; because the average value of AC over full cycle is zero.

The source of energy generation is the mechanical energy or ration of armature coil.



NODIA

134. Using phaser diagram for a series LCR circuit connected to an AC source of voltage $V = V_0 \sin \omega t$, derive the relation for the current flowing in the circuit and the phase angle between the voltage across the resistor and the net voltage in the circuit.

Draw a plot showing the variation of the current I as a function of angular frequency 'ω' of the applied AC source for the two cases of a series combination of

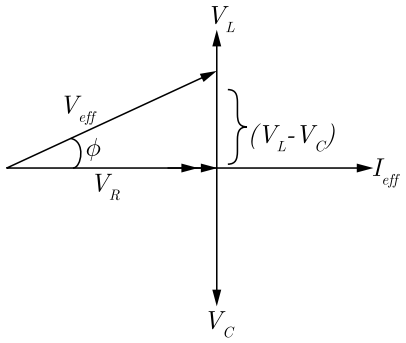
(i) inductance L_1, Capacitance C_1 and resistance R_1 and

(ii) inductance L_2, Capacitance C_2 and resistance R_2 where $R_2 > R_1$

Write the relation between L_1, C_1 and L_2, C_2 at resonance. Which one of the two would be better suited for fine tuning in a receiver set? Give reason.

Ans : **Comp 2013**

(a) For I_{eff} flow of current through each element R, L and C, effective voltage across the combination can be given as.



$$\vec{V}_{eff} = \hat{i}\,V_R + \hat{j}\,(V_L - V_C)$$

$$|V_{eff}| = \sqrt{|V_R|^2 + (V_L - V_C)^2}$$

$$I_{eff}\,Z = \sqrt{(I_{eff}\,R)^2 + (I_{eff}\,X_L - I_{eff}\,X_C)^2}$$

$$|Z| = \sqrt{R^2 + (X_L - X_C)^2}$$

Effective current flow,

$$I_{eff} = \frac{E_{eff}}{Z} = \frac{E_{eff}}{\sqrt{R^2 + (X_L - X_C)^2}}$$

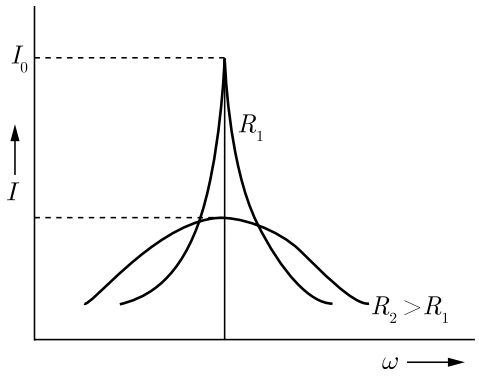
Phase angle between V_R and V_{eff} is

$$\cos\phi = \frac{V_R}{V_{eff}} = \frac{V_R}{\sqrt{V_R^2 + (V_L - V_C)^2}}$$

(i) $I = I_0 \sin(\omega t - \phi)$ For $V_L > V_C$ or $X_L > X_C$

(ii) $I = I_0 \sin(\omega t + \phi)$ For $V_L < V_C$ or $X_L < X_C$

Variation of the current I as a function of angular frequency ω



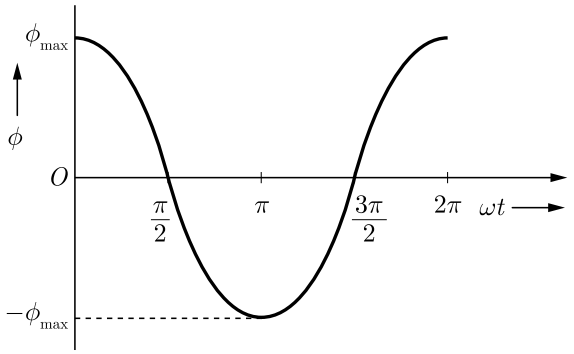
At resonance, when maximum current flows through the circuit.

$$\omega_r = \frac{1}{\sqrt{L_1 C_1}} = \sqrt{\frac{1}{L_2 C_2}}$$

$$L_1 C_1 = L_2 C_2$$

$$\frac{L_1}{L_2} = \frac{C_2}{C_1}$$

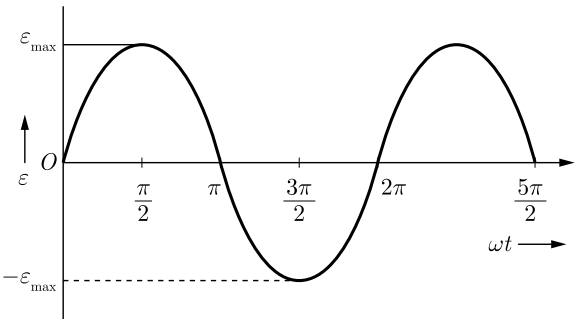
For fine tuning in the receiver set, combination $L_1 C_1$ and R_1 is better because maximum current flows through the circuit.



From lenz' law, induced emf.

$$\varepsilon - \frac{d\phi}{dt} = -|B||A|\frac{d}{dt}\cos\omega t$$

$$= |B|A\omega\sin\omega t$$



NUMERICAL QUESTIONS

135. A light bulb is rated at 100 W for a 220 V AC supply. Calculate the resistance of bulb.

Ans : **Main 2012**

In case of AC,

$$P_{av} = \frac{V_{rms}^2}{R} = \frac{V_{eff}^2}{R}$$

$$R = \frac{V_{rms}^2}{p_{av}} = \frac{220 \times 220}{100} = 484\,\Omega$$

136. At resonance, what is the relation between impedance of a series L-C-R circuit and its resistance R?

Ans : **SQP 2004**

At resonance, $X_L = X_C$

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{R^2 + 0} = R$$

At resonance net impedance is equal to resistance (R).

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$$= I_0^2 R \int_0^T \left[\frac{1-\cos 2\omega t}{2}\right] dt$$

$$\left[\text{Since, } \sin^2\omega t = \frac{1-\cos 2\omega t}{2}\right]$$

$$= \frac{I_0^2 R}{2}\int_0^T (1-\cos 2\omega t)\, dt$$

$$= \frac{I_0^2 R}{2}\left[\int_0^T dt - \int_0^T \cos 2\omega t dt\right]$$

$$= \frac{I_0^2 R}{2}\left[\left| t \right|_0^T - \left| \frac{\sin 2\omega t}{2\omega} \right|_0^T\right]$$

$$= \frac{I_0^2 R}{2}\left[(T-0) - \frac{1}{2\omega}\left|\sin 2\omega T - \sin 0^\circ\right|\right]$$

$$= \frac{I_0^2 R}{2}\left[T - \frac{1}{2\omega}\left|\sin 2 \times 2\pi - 0\right|\right]$$

$$[\text{Since, } \omega T = 2\pi]$$

$$= \frac{I_0^2 R}{2}\left[T - \frac{1}{2\omega}\left|0 - 0\right|\right]$$

$$[\text{Since, } \sin 4\pi = 0]$$

$$= \frac{I_0^2 RT}{2} \qquad ...(2)$$

If I_{rms} is rms value of alternating current and H is the heat produced by rms current (I_{rms}), then

$$H = I_{\text{rms}}^2 RT \qquad ...(3)$$

On comparing Equation (2) and (3), we get

$$I_{\text{rms}}^2 RT = \frac{I_0^2 RT}{2}$$

$$I_{\text{rms}}^2 = \frac{I_0^2}{2}$$

$$I_{\text{rms}} = \sqrt{\frac{I_0^2}{2}} = \frac{I_0}{\sqrt{2}} = 0.707 I_0$$

$$I_{\text{rms}} = 70.7\% \text{ of } I_0$$

131. Describe briefly, with the help of a labelled diagram, the working of a step up transformer.

Ans : **SQP 2016, 2011**

Transformer is a device by which an alternating voltage may be decreased or increased. It is based on the principle of mutual-induction.

Construction : It consists of laminated core of soft iron, on which two coils of insulated copper wire are separately wound. These coils are kept insulated from each other and from the iron-core, but are coupled through mutual induction. The number of turns in these coils are different. Out of these coils one coil is called primary coil and other is called the secondary coil. The terminals of primary coils are connected to AC mains and the terminals of the secondary coil are connected to external circuit in which alternating current of desired voltage is required. Transformers are of two types :

(i) **Step-up Transformer :** It transforms the alternating low voltage to alternating high voltage and in this the number of turns in secondary coil is more than that in primary coil (i.e., $N_s > N_P$).

(ii) **Step-down Transformer :** It transforms the alternating high voltage to alternating low voltage and in this the number of turns in secondary coil is less than that in primary coil (i.e., $N_s < N_P$).

Working : When alternating current source is connected to the ends of primary coil, the current changes continuously in the primary coil; due to which the magnetic flux linked with the secondary coil changes continuously, therefore the alternating emf of same frequency is developed across the secondary.

Let N_P be the number of turns in primary coil, N_S the number of turns in secondary coil and ϕ the magnetic flux linked with each turn. We assume that there is no leakage of flux so that the flux linked with each turn of primary coil and secondary coil is the same. According to Faraday's laws the emf induced in the primary coil

$$\varepsilon_P = -N_P \frac{\Delta\phi}{\Delta t} \qquad ...(1)$$

and emf induced in the secondary coil

$$\varepsilon_s = -N_s \frac{\Delta\phi}{\Delta t} \qquad ...(2)$$

From eq. (1) and eq. (2)

$$\frac{\varepsilon_s}{\varepsilon_p} = \frac{N_s}{N_p} \qquad ...(3)$$

If the resistance of primary coil is negligible, the emf (ε_p) induced in the primary coil, will be equal to the applied potential difference (V_P) across its ends. Similarly if the secondary circuit is open, then the potential difference V_s across its ends will be equal to the emf (ε_s) induced in it; therefore,

$$\frac{V_s}{V_p} = \frac{\varepsilon_s}{\varepsilon_p} = \frac{N_s}{N_p} = r(say) \qquad ...(4)$$

Where $r = \frac{N_s}{N_p}$ is called the transformation ratio. If i_p and i_s are the instantaneous currents in primary and secondary coils and there is no loss of energy.

For about 100% efficiency,

Power in primary = power in secondary

$$V_p i_p = V_s i_s$$

$$\frac{i_s}{i_p} = \frac{V_p}{V_s} = \frac{N_p}{N_s} = \frac{1}{r} \qquad ...(v)$$

NODIA

145. An AC generator generates an emf ε, where $\varepsilon = 314\sin(50\pi t)$ volt. Calculate the frequency of the emf ε.

Ans : **Main 2017, 2011**

Given,

$$\varepsilon = 314\sin(50\pi t)\ \text{V}$$

On comparing with,

$$\varepsilon = \varepsilon_0 \sin\omega t$$

We get, $\omega = 50\pi$

so, $\omega = 2\pi f$

$$f = \frac{2\pi}{\omega}$$

$$= \frac{2\pi}{50\pi} = \frac{1}{25} = 0.04$$

146. A power transmission line needs input power at 2300 V to a step down transformer with its primary windings having 4000 turns. What should be the number of turns in the secondary winding in order to get output power at 230 V?

Ans : **SQP 2019**

Given $V_P = 2300$ Vott, $N_P = 4000$ turns,

$V_S = 230$ Vott, $N_S = ?$

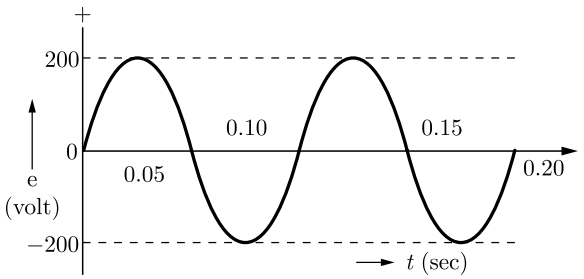
We have, $\frac{V_S}{V_P} = \frac{N_S}{N_P}$

$$N_S = \frac{V_S}{V_P} \times N_P$$

$$= \frac{230}{2300} \times 4000$$

$$= 400 \text{ turns}$$

147. Figure below shows emf e generated by an AC generator versus time t.



What is the frequency of emf?

Ans : **Main 2022 (Sem-I), 2010**

From the graph,

Time period $T = 0.10$ s

Frequency, $f = \frac{1}{T} = \frac{1}{0.10} = 10$ Hz

148. The electric main in a house is marked 220 V − 50 Hz. Write down the equation for the instantaneous voltage. The only variable in the equation should be t.

Ans : **Main 2005**

Given, $V_{\text{rms}} = 220$ Volt, $f = 50$ Hz

The equation of an alternating voltage can be written as

$$V = V_0 \sin\omega t$$

where, $V_0 =$ peak voltage

$$V_{\text{rms}} = \frac{V_0}{\sqrt{2}}$$

$$= \sqrt{2}\ V_{\text{rms}} = \sqrt{2} \times 220 = 311\ \text{V}$$

$$V = 311\sin 3\pi \times 50t \qquad [\omega = 2\pi f]$$

$$V = 311\sin 100\pi t$$

149. An AC generator generates an emf, which is given by $e = 311\sin(240\,\pi t)$ V. Calculate

(i) frequency of the emf

(ii) rms value of the emf

Ans : **Main 2023**

Given,

$$e = 311\sin(240\pi t)\ \text{V}$$

After comparing with standard equation of e.m.f

(i) $\omega t = 240\pi t$

$$2\pi f = 240\pi$$

$$f = 120\ \text{Hz}$$

(ii) $E_{\text{rms}} = 0.707 \times 311$

$$= 219.87\ \text{V}$$

150. An AC source of emf $E = 200\sin\omega t$ is connected to a resistor of 50 Ω. Calculate

(i) average current (I_{av}) and

(ii) root mean square (rms) value of emf.

Ans : **Main 2019**

Given,

$$E = 200\sin\omega t$$

$$E_0 = 200\ \text{V}$$

(i) Peak current, $I_0 = \frac{E_0}{R} = \frac{200}{50} = 4$ A

Average current, $I_{av} = 0.637 I_0$

$$= 0.637 \times 4 = 2.548\ \text{A}$$

(ii) rms value of emf,

$$E_{\text{rms}} = \frac{E_0}{\sqrt{2}} = \frac{200}{\sqrt{2}} = 141.42\ \text{V}$$

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$$= 2 \times \frac{25\,\text{N}}{N}$$

$$= 50\,\text{A}$$

where, I_P = current in primary

161. What is the value of current, flowing through an inductor of inductance 1 H and having negligible resistance when connected to an AC source of 200 V and 50 Hz?

Ans : SQP 2007, 2004

Given,

Inductance, $L = 1\,\text{H}$

Voltage, $V = 200\,\text{Volt}$

Frequency, $f = 50\,\text{Hz}$

angular frequency,

$$\omega = 2\pi f = 2 \times 3.14 \times 50$$

$$= 314\,\text{rad–s}^{-1}$$

Therefore, reactance of the inductor,

$$X_L = \omega L = 314 \times 1 = 314\,\Omega$$

We also know that current flowing through the inductor,

$$I = \frac{V}{X_L} = \frac{200}{314} = 0.64\,\text{A}$$

162. An alternating voltage given by $V = 70\sin 100\pi t$ is connected across a pure resistor of $25\,\Omega$. Find

(i) the frequency of the source.

(ii) the R.M.S. current through the resistor.

Ans : Comp 2016, 2012

Given, $V = 70\sin 100\pi t$

On comparing with standard equation,

$$V = V_0 \sin \omega t$$

$$V_0 = 70\,\text{Volt}$$

$$\omega = 100\pi\,\text{rad/s}$$

(i) As,

$$\omega = 2\pi v = 100\pi$$

Frequency of the source,

$$U = 50\,\text{Hz}$$

(ii) $$V_{\text{rms}} = \frac{V_0}{\sqrt{2}} = \frac{70}{\sqrt{2}}$$

Hence, $$I_{\text{rms}} = \frac{V_{\text{rms}}}{R} = \frac{\left(\frac{70}{\sqrt{2}}\right)}{25}$$

$$= \frac{70}{1.414 \times 25}$$

$$= 1.98\,\text{A}$$

163. An alternating voltage given by $V = 280\sin 50\pi t$ is connected across a pure resistor of $40\,\Omega$. Find

(i) the frequency of the source.

(ii) the r.m.s. current through the resistor.

Ans : Main 2012

Given, $V = 280\sin 50\pi t,\ R = 40\,\Omega$

Comparing it with standard equation,

$$V = V_0 \sin \omega t$$

$$V_0 = 280\,\text{Volt}$$

$$\omega = 50\pi\,\text{rad/s}$$

(i) As, $$\omega = 2\pi v$$

$$2\pi v = 50\pi$$

Frequency of AC, $$v = \frac{50}{2} = 25\,\text{Hz}$$

(ii) $$V_{\text{rms}} = \frac{V_0}{\sqrt{2}} = \frac{280}{\sqrt{2}}\text{V}$$

Hence, $$I_{\text{rms}} = \frac{V_{\text{rms}}}{F} = \frac{280}{\sqrt{2} \times 40}$$

$$I_{\text{rms}} = \frac{280}{1.414 \times 40}$$

$$= 4.95\,\text{A}$$

164. Show that $I_{\text{rms}} = \frac{I_0}{\sqrt{2}}$, where I_{rms} is the root mean square value of alternating current and I_0 is the peak value.

Ans : Main 2006

Let the alternating current is $i = i_0 \sin \omega t$

Mean of square value of current,

$$< i^2 > = \frac{1}{T}\int_0^T t^2\,dt \quad \text{[for a complete cycle]}$$

$$= \frac{1}{T}\int_0^T i_0^2 \sin^2 \omega t\,dt$$

$$= \frac{i_0^2}{T}\int_0^T \left(\frac{1 - \cos 2\omega t}{2}\right) dt$$

$$= \frac{i_0^2}{2T}\left[t - \frac{\sin 2\omega t}{2\omega}\right]_0^T$$

$$= \frac{i_0^2}{2T}[T - 0] = \frac{i_0^2}{2}$$

Now by taking roots of mean square value of current

i.e. $$i_{\text{rms}} = \sqrt{< i^2 >} = \sqrt{i_0^2/2} = \frac{i_0}{\sqrt{2}}$$

where, i_{rms} = root of mean square value,

i_0 = peak value of current

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$$R = 10\,\Omega$$

Now, Q-factor $= \frac{1}{R}\sqrt{\frac{L}{C}}$

$$= \frac{1}{10}\sqrt{\frac{2}{2\times10^{-6}}} = \frac{1}{10\times10^{-3}}$$

$$= \frac{1}{10^{-2}} = 100$$

Quality factor is also defined as,

$$Q = 2\pi f \times \frac{\text{Energy stored}}{\text{Power loss}}$$

So, higher the value of Q means the energy loss is at lower rate relative to the energy stored, i.e. the oscillations will die slowly and damping would be less.

157. In a LCR-circuit, the potential difference between the terminals of the inductance is 60 V, between terminals of the capacitor is 30 V and that between the terminals of the resistance is 40 V. What is the supply voltage?

Ans : **Comp 2011**

Given,

Potential difference across inductance,

$$V_L = 60 \text{ Volt}$$

Potential difference across capacitor,

$$V_C = 30 \text{ Volt}$$

and potential difference across resistance,

$$V_R = 40 \text{ Volt}$$

supply voltage in LCR-circuit,

$$V = \sqrt{V_R^2 + (V_L - V_C)^2}$$

$$= \sqrt{(40)^2 + (60-30)^2}$$

$$= \sqrt{1600 + 900}$$

$$= \sqrt{2500} = 50 \text{ Volt}$$

158. The ratio of numbers of turns of primary coil to secondary coil in a transformer is 2 : 3. If a cell of 6 V is connected across the primary coil, What is the voltage across the secondary coil?

Ans : **Comp 2018**

Given,

No. of turns in primary,

$$N_P = 2\,\text{N}$$

No. of turns in secondary coil,

$$N_S = 3\,\text{N}$$

Supply voltage on primary,

$$V_P = 6 \text{ Volt}$$

relation between voltages and no. of turns in primary and secondary is,

$$\frac{V_P}{V_S} = \frac{N_P}{N_S}$$

$$V_S = V_P \times \frac{N_S}{N_P}$$

$$= 6 \times \frac{3\,\text{N}}{2\,\text{N}} = 9 \text{ Volt}$$

where, $V_S =$ voltage across secondary coil

159. A step-up transformer has transformation ratio of 5:3. What is the voltage in the secondary, if voltage in the primary is 60 V?

Ans : **Main 2024**

Given,

No. of turns in secondary,

$$N_S = 5\,\text{N}$$

No. of turns in primary,

$$N_P = 3\,\text{N}$$

Voltage in primary,

$$V_P = 60 \text{ Volt}$$

relation between voltages and number turns in primary and secondary is,

$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$

$$V_S = V_P \times \frac{N_S}{N_P}$$

$$= 60 \times \frac{5\,\text{N}}{3\,\text{N}} = 100 \text{ Volt}$$

where, $V_S =$ voltage in secondary

160. A step-up transformer operates on a 230 V line supplies a current of 2 A. The ratio of primary and secondary winding is 1:25. What is the current in the primary coil?

Ans : **Main 2010**

Given,

Voltage in primary, $V_P = 230$ Volt

Current in secondary, $I_S = 2\,\text{A}$

No. of windings in primary,

$$N_P = N$$

No. of windings in secondary,

$$N_S = 25\,\text{N}$$

relation between currents and no. of turns in primary and secondary is,

$$\frac{I_P}{I_S} = \frac{N_S}{N_P}$$

$$I_P = I_S \times \frac{N_S}{N_P}$$

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151. A circuit consists of a resistor, an inductor and a capacitor connected in series. If resistance of the resistor is $25\,\Omega$ and the value of inductive reactance is equal to capacitive reactance, What is the net impedance of the circuit?

Ans : **Main 2017**

Given,

Resistance, $R = 25\,\Omega$

Inductive reactance = capacitive reactance

i.e., $X_L = X_C$

Net impedance of the LCR-circuit,

$$\begin{aligned} Z &= \sqrt{R^2 + (X_L - X_C)^2} \\ &= \sqrt{(25)^2 + (X_L - X_L)^2} \\ &= 25\,\Omega \end{aligned}$$

152. In a ideal transformer, voltage and current in primary are 200 V and 2 A respectively. If voltage in the secondary is 2000 V, what is the current in the secondary coil of transformer?

Ans : **SQP 2008, 2006**

Voltage in primary, $V_P = 200$ Volt

Current in primary, $I_P = 2$ A

Voltage in secondary, $V_S = 2000$ Volt

relation between currents and voltages in primary and secondary is,

$$\frac{I_P}{I_S} = \frac{V_S}{V_P}$$

$$I_S = I_P \times \frac{V_P}{V_S}$$

$$= 2 \times \frac{200}{2000} = 0.2\text{ A}$$

where, $I_S =$ current in secondary

153. In an experiment, 200 V AC is applied at the ends of an LCR-circuit. The circuit consists of an inductive reactance of $50\,\Omega$, capacitive reactance of $35\,\Omega$ and ohmic resistance of $20\,\Omega$. What is the impedance of the circuit?

Ans : **Comp 2014**

Given,

Supply voltage, $V = 200$ Volt

Inductive reactance, $X_L = 50\,\Omega$

Capacitive reactance, $X_C = 35\,\Omega$

Ohmic resistance, $R = 20\,\Omega$

impedance of the LCR-circuit,

$$\begin{aligned} Z &= \sqrt{R^2 + (X_L - X_C)^2} \\ &= \sqrt{(20^2) + (50 - 35)^2} \\ &= \sqrt{400 + 225} = \sqrt{625} = 25\,\Omega \end{aligned}$$

154. When an alternating emf, $e = 300\sin(100\pi t + \pi/6)$ volt is applied to a circuit, the current I through it is $I = 5.0\sin(100\pi t - \pi/6)$ ampere. Then, find the average power consumed by the circuit.

Ans : **Main 2009**

Given $I = 5\sin\left(100\pi t - \frac{\pi}{6}\right)$

$e = 300\sin\left(100\pi t + \frac{\pi}{6}\right)$

average power consumed

$$P_{\text{av}} = E_{\text{rms}} I_{\text{rms}} \cos\phi = \frac{E_0}{\sqrt{2}} \times \frac{I_0}{\sqrt{2}} \cos\phi$$

where, $E_0 =$ peak emf $= 300$ V

$I_0 =$ peak current $= 5$ A

$\cos\phi =$ power factor $= \cos 60^\circ = \frac{1}{2}$

$$\left[\begin{matrix}\phi = \phi_1 - \phi_2 \\ = \frac{\pi}{6} + \frac{\pi}{6} = \frac{\pi}{3}\end{matrix}\right]$$

$$P_{\text{av}} = \frac{300}{\sqrt{2}} \times \frac{50}{\sqrt{2}} \times \frac{1}{2} = 3750\text{ W}$$

155. Reactance of a capacitor of capacitance C for an alternating current of frequency $\frac{400}{\pi}$ Hz is $25\,\Omega$. What is the value of C?

Ans : **Main 2025**

Given,

Capacitance of capacitor $= C$

Frequency of current, $f = \frac{400}{\pi}$Hz

Reactance of capacitor, $X_C = 25\,\Omega$

reactance of the capacitor,

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$$

$$C = \frac{1}{2\pi f X_C}$$

$$= \frac{1}{2\pi \times \frac{400}{\pi} \times 25}$$

$$= 50 \times 10^{-6}$$

$$F = 50\,\mu\text{F}$$

156. Calculate the quality factor of a series LCR circuit with $L = 2.0$ H, $C = 2\,\mu$F and $R = 10\,\Omega$. Mention the significance of quality factor in LCR circuit.

Ans : **SQP 2013, 2010**

Given, $L = 2.0$ H

$C = 2\,\mu\text{F} = 2 \times 10^{-6}$F

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165. A current of 4 A flows in a coil when connected to a 12 V DC source. If the same coil is connected to a $12\,V$, 8 Hz AC source, a current 2.4 A flows in the coil. Calculate the coefficient of self-inductance L of the coil.

Ans : **Main 2005, 2001**

For DC source, the inductor will act as short circuit and only resistor has to be taken for calculation of current.

Now for DC source connected to the circuit

$$X_L = \omega L = 0 \qquad [\omega = 0]$$

So, resistance, $R = \frac{E}{I} = \frac{12\text{ V}}{4\text{ A}} = 3\,\Omega$

When the coil is connected to AC source, then

$$i = \frac{E}{\sqrt{R^2 + (\omega L)^2}} \quad \left[Z = \sqrt{R^2 + (\omega L)^2}\right]$$

$$2.4 = \frac{12}{\sqrt{3^2 + (2\pi fL)^2}}$$

$$9 + (2\pi fL)^2 = \left(\frac{12}{2.4}\right)^2 = 25$$

$$(2\pi fL)^2 = 25 - 9 = 16$$

$$2\pi fL = 4$$

$$L = \frac{1}{2\pi f} \times 4 = \frac{1}{2\pi \times 8} \times 4 \quad [f = 8\text{ Hz}]$$

$$L = \frac{1}{4\pi}\text{ H} = 0.0795\text{ H}$$

166. In a L-C-R circuit, all components connected in series, the emf and the current flowing in the circuit are given by the following equations.

$$\varepsilon_0 = 200\sin\left(314t + \frac{\pi}{6}\right)\text{V},\ I = 5\sin 314t\text{ A}$$

Obtain

(i) the peak values of current and emf.

(ii) the frequency of the AC source.

(iii) the phase difference between current and emf.

Ans : **Main 2000**

According to the given equations in the question,

$$E_0 = 200\sin\left(314t + \frac{\pi}{6}\right)$$

and $I = 5\sin(314t)\text{ A}$

Comparing above two equations with standard equation.

(i) Peak value of the current,

$$I_0 = 5\text{ A and emf, } \varepsilon_0 = 200\text{ V}$$

(ii) $\omega = 2\pi f = 314$

$$f = \frac{314}{2 \times 3.14} = 50\text{ Hz}$$

(iii) The phase difference between the current and emf,

$$\phi = \frac{\pi}{6} = 30^\circ$$

167. A circuit is set up by connecting inductance $L = 100\text{ mH}$, resistor $R = 100\,\Omega$ and a capacitor of reactance $200\,\Omega$ in series. An alternating emf of $150\sqrt{2}$ V, $\frac{500}{\pi}$ Hz is applied across this series combination. Calculate the power dissipated in the resistor.

Ans : **Main 2019**

Here, $L = 100 \times 10^{-3}$ H, $R = 100\,\Omega$

$X_C = 200\,\Omega$, $V_{\text{rms}} = 150\sqrt{2}$ Volt

$$V = \frac{500}{\pi}\text{ Hz}$$

Inductive reactance,

$$X_L = \omega L = 2\pi vL$$

$$= 2 \times \pi \times \frac{500}{\pi} \times 100 \times 10^{-3}$$

$$= 100$$

Impedance of circuit,

$$Z = \sqrt{R^2 + (X_C - X_L)^2}$$

$$= \sqrt{(100)^2 + (200 - 100)^2}$$

$$= \sqrt{20000} = 100\sqrt{2}$$

$$I_{\text{rms}} = \frac{V_{\text{rms}}}{Z} = \frac{150\sqrt{2}}{100\sqrt{2}}\ \frac{3}{2}$$

Power dissipated

$$= (I_{\text{rms}})^2 R = \frac{9}{4} \times 100 = 225\text{ W}$$

168. The equation of alternating current is $I = 20\sin 200\,\pi t$. Find out the frequency, peak value and r.m.s. value of the current.

Ans : **SQP 2015**

Given, $I = 20\sin 200\,\pi t$ ...(1)

The standard equation of alternating current is given by,

$$I = I_0 \sin\omega t \qquad ...(2)$$

where, I_0 = Peak value of current

After comparing Eq. (1) with (2), we get

Peak value of current,

$$I_0 = 20A$$

$$\omega = 200\,\pi$$

$$2\pi f = 200\pi \qquad (\text{Since, } \omega = 2\pi f)$$

Frequency, $f = 100\text{ Hz}$

$$I_{\text{rms}} = \frac{I_0}{\sqrt{2}} = \frac{20}{\sqrt{2}}$$

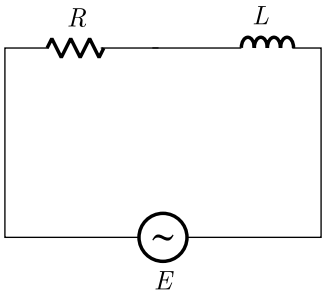
Ans : **Main 2004**

Given,

$$R = 30\,\Omega,\ X_L = 40\,\Omega$$

(i) For an R-L circuit, we have to use

Impedance, $Z = \sqrt{R^2 + X_L^2}$ ...(1)



$$Z = \sqrt{(30)^2 + (40)^2} = 50\,\Omega$$

(ii) $\phi =$ phase difference

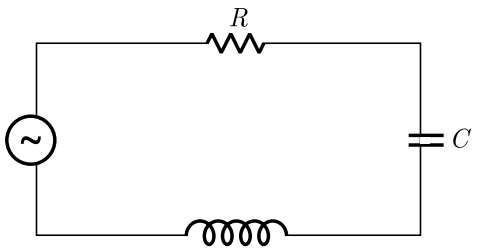
$$= \tan^{-1}\left(\frac{X_L}{R}\right)$$

$$= \tan^{-1}\left(\frac{40}{30}\right) = 53^\circ$$

(iii) Peak value of current,

$$I_0 = \frac{V_0}{Z} = \frac{220}{50} = 4.4\ \text{A}$$

183. The figure shows a series LCR circuit with $L = 100\,\text{H}$, $C = 40\mu\text{F}$ $R = 60\,\Omega$ connected to a variable frequency 240 V source. Calculate



(i) the angular frequency of the source which derives the circuit at resonance.

(ii) the current at the resonating frequency.

(iii) the rms potential drop across the inductor at resonance.

Ans : **Main 2021**

Given, $L = 10\,\text{H},\ C = 40\,\mu\text{F},$

$$R = 60\,\Omega,\ V_{rms} = 240\ \text{Volt}$$

(i) resonating angular frequency,

$$\omega_0 = \frac{1}{\sqrt{LC}} = \sqrt{\frac{1}{10 \times 40 \times 10^{-6}}}$$

$$\omega_0 = \frac{1}{20 \times 10^{-3}} = 50\ \text{rad/s}$$

(ii) Current at resonating frequency,

$$I_{rms} = \frac{V_{rms}}{Z} = \frac{V_{rms}}{R}$$

(Since, at resonance, $Z = R$)

$$= \frac{240}{60} = 4\text{A}$$

(iii) Since inductive reactance, $X_L = \omega L$

At resonance,

$$X_L = \omega_0 L = 50 \times 10 = 500\,\Omega$$

Potential drop across to inductor,

$$V_{rms} = I_{rms} \times X_L$$

$$= 4 \times 500 = 2000\ \text{Volt}$$

184. A $400\,\Omega$ resistor, a 3 H inductor and a $5\,\mu\text{F}$ capacitor are connected in series to a 220 V, 50 Hz AC source. Calculate the

(a) impedance of the circuit.

(b) current flowing through the circuit.

Ans : **Main 2020, 2017**

Given, capacitance,

$$C = 5\,\mu\text{F} = 5 \times 10^{-6}\,\text{F}$$

Resistance, $R = 400\,\Omega$

Inductance, $L = 3\,\text{H}$

V_{rms} value of voltage,

$$E_V = 220\ \text{V}$$

Frequency, $U = 50\,\text{Hz}$

(a) Since, capacitive reactance,

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi v C}$$

$$= \frac{1}{2 \times 3.14 \times 50 \times 5 \times 10^{-6}}$$

$$X_C = 636.9\,\Omega$$

and inductive reactance

$$X_L = \omega L = 2\pi v L$$

$$= 2 \times 3.14 \times 50 \times 3$$

$$= 942\,\Omega$$

Impedance, $Z = \sqrt{R^2 + (X_L - X_C)^2}$

$$= \sqrt{(400)^2 + (942 - 636.9)^2}$$

$$= \sqrt{(400)^2 + (305.1)^2}$$

$$= 503.1\,\Omega$$

(b) Current flowing through the circuit,

$$I = \frac{E}{Z} = \frac{220}{503.1} = 0.437\ \text{A}$$

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$$\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$$
$$= \tan^{-1}\left(\frac{10\sqrt{3}}{10}\right)$$
$$= \tan^{-1}(\sqrt{3}) = 60^\circ$$

173. An alternating emf of 200 V, 50 Hz is applied to an L-R circuit, having a resistance R of 10 Ω and an inductance L of 0.05 H connected in series. Calculate

(a) impedance.

(b) current flowing in the circuit.

Ans : **Main 2019**

Given, $V_{rms} = 200$ Volt, $L = 0.05$ H,

$R = 10\,\Omega$, $f = 50$ Hz

Angular frequency,

$$\omega = 2\pi f$$
$$= 2\pi \times 50$$
$$= 100\pi \text{ rad/s}$$

Inductive reactance,

$$X_L = \omega L$$
$$= 100\pi \times 0.05$$
$$= 5\pi\,\Omega$$

(a) Impedance,

$$Z = \sqrt{R^2 + X_L^2}$$
$$= \sqrt{(10)^2 + (5\pi)^2}$$
$$= \sqrt{100 + 25\pi^2} = \sqrt{346.74}$$
$$= 18.614\,\Omega$$

(b) Current flowing in the circuit,

$$I = \frac{V_{rms}}{Z} = \frac{200}{18.614} = 10.744 \text{ A}$$

174. An AC generator generating an emf E given by $E = 311\sin(10t)$ is connected to a 44 Ω resistor. Calculate

(a) rms value of AC flowing through the resistor

(b) frequency of the current

(c) mean value of emf generated by the generator in time interval 0.06 s to 0.08 s

Ans : **SQP 2018**

Given, $E_0 = 311$ V, $R = 44\,\Omega$, $\omega = 10$

(a) $$E_{rms} = \frac{E_0}{\sqrt{2}} = \frac{311}{\sqrt{2}} = \frac{311}{1.41} = 220 \text{ V}$$

$$I_{rms} = \frac{E_{rms}}{R} = \frac{220}{44} = 5 \text{ A}$$

(b) $$\omega = 2\pi v$$
$$2\pi v = 10$$
$$v = \frac{10}{2\pi} = \frac{10 \times 7}{2 \times 22} = 1.59 \text{ Hz}$$

(c) $$T = \frac{2\pi}{\omega} = \frac{2 \times 3.14}{10} = \frac{6.28}{10} = 0.628$$

$$E_{avg} = \frac{1}{T}\int_{t_1}^{t_2} E(t)\,dt = \frac{1}{T}\int_{t_1}^{t_2} 311\sin(10t)\,dt$$
$$= \frac{1}{0.628}\int_{0.06}^{0.08} 311\sin(10t)\,dt$$
$$= -\frac{311}{0.628 \times 10}[\cos\omega t_2 - \cos\omega t_1]$$
$$= -\frac{311}{6.28}[\cos 10 \times 0.08 - \cos 10 \times 0.06]$$
$$= 49.5[0.696 - 0.825] = 6.38 \text{ V}$$

175. Find the inductance of a choke coil needed to run an arc lamp with an AC source of 100 V supply at 50 Hz. The arc runs at 10 A current and has an effective resistance of 4 Ω.

Ans : **Main 2004**

Given $V = 100$ Volt, $f = 50$ Hz,

$I = 10$ A, $R = 4\,\Omega$

We know, that, $V = IZ$

where, $Z = \sqrt{R^2 + X_L^2}$

where, I is current and X_L is impedance.

$$Z = \frac{V}{I} = \frac{100}{10} = 10\,\Omega$$
$$Z = \sqrt{R^2 + (X_L)^2}$$
$$(10)^2 = (4)^2 + (X_L)^2$$
$$\sqrt{100 - 16} = X_L$$
$$\sqrt{84} = X_L$$
$$X_L = \omega L$$
$$X_L = 2\pi f L$$
$$L = \frac{X_L}{2\pi f}$$
$$= \frac{\sqrt{84}}{2\pi \times 50} = 29 \text{ mH}$$

176. In a transformer, the output current and voltage are respectively 4 A and 20 V. If ratio of no. of turns in primary to secondary is 2 : 1, what is the input current and voltage?

Ans : **SQP 2016**

Given,

Output current in secondary,

$$I_S = 4 \text{ A}$$

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Output Voltage in secondary,

$$V_S = 20 \text{ Volt}$$

No. of turns in primary,

$$N_P = 2\,\text{N}$$

and no. of turns in secondary,

$$N_S = N$$

relation between currents and number of turns in primary and secondary is,

$$\frac{I_P}{I_S} = \frac{N_S}{N_P}$$

$$I_P = I_S \times \frac{N_S}{N_P}$$

$$= 4 \times \frac{N}{2\,\text{N}} = 2\,\text{A}$$

where, I_P = current in primary

We also know that relation between voltage and no. of turns in primary and secondary is:

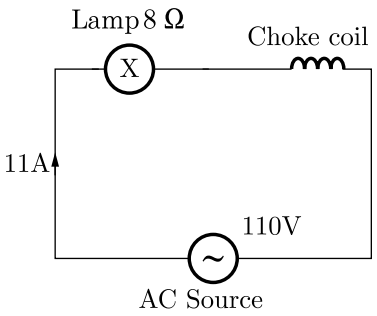
$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$

or $$V_P = V_S \times \frac{N_P}{N_S}$$

$$= 20 \times \frac{2\,\text{N}}{N} = 40 \text{ Volt}$$

where, V_P = input voltage in primary

177. A lamp with a resistance of $8\,\Omega$ is connected to a choke coil as shown in the figure.



This arrangement is connected to an alternating source 110 V. The current in the circuit is 11 A. The frequency of the AC is 60 Hz. Then, find the

(i) impedance of the circuit.

(ii) value of inductive reactance of the choke coil.

Ans : **Main 2000**

(i) Given,

Applied emf = 110 V,

current, $I = 11\,\text{A}$

Impedance of the circuit,

$$Z = \frac{E}{I} = \frac{110}{11} = 10\,\Omega$$

(ii) As we know

Impedance, $Z = \sqrt{R^2 + X_L^2}$

$$X_L = \sqrt{Z^2 - R^2}$$

$$= \sqrt{10^2 - 8^2} = \sqrt{100 - 64}$$

$$= \sqrt{36} = 6\,\Omega$$

The inductive reactance of the chock coil is

$$X_L = 6\,\Omega$$

178. Determine the current quality factor at resonance for a series LCR circuit with $L = 1.00$ mH and $C = 1.00nF$ and $R = 100\,\Omega$ connected to an AC source having peak voltage of 100 V.

Ans : **Main 2014, 2009**

Given, $L = 1.00\,\text{mH} = 1 \times 10^{-3}\text{H}$

$$C = 1.00\,n\text{F} = 1 \times 10^{-9}\,\text{F}$$

$$R = 100\,\Omega$$

$$E_0 = 100 \text{ Volt}$$

$$I_0 = \frac{E_0}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}}$$

$$= \frac{E_0}{Z} \left\{ \begin{matrix} \text{at resonance } \omega L \frac{1}{\omega C} \\ \text{Hence,} \qquad Z = R \end{matrix} \right\}$$

Hence, $I = \frac{V}{R} = \frac{100}{100}$

$$I_v = \frac{I_0}{\sqrt{2}} = \frac{1}{\sqrt{2}} = \frac{\sqrt{2}}{2}$$

$$= \frac{1.44}{2}$$

$$= 0.707\text{A} \qquad [\text{Hence } I_0 = IA]$$

$$Q = \frac{1}{2}\sqrt{\frac{L}{C}}$$

$$= \frac{1}{100}\sqrt{\frac{10 \times 10^{-3}}{1.0 \times 10^{-9}}}$$

$$= \frac{1}{100} \times 10^3 = 10$$

179. In a series LCR circuit with an AC source of effective voltage 50V, frequency $v = \frac{50}{\pi}$Hz, $R = 300\,\Omega$, $C = 20\,\mu\text{F}$ and $L = 1.0\,\text{H}$. Find the r.m.s. current in the circuit.

Ans : **Comp 2017**

Given, $L = 1.0\,\text{H}$,

$$C = 20\,\mu\text{F} = 20 \times 10^{-6}\,\text{F}$$

$$R = 300\,\Omega$$

$$V_{\text{rms}} = 50 \text{ Volt}$$

and $$v = \frac{50}{\pi}\,\text{Hz}$$

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Inductive reactance,

$$X_L = \omega L = 2\pi v L$$
$$= 2 \times \pi \times \frac{50}{\pi} \times 1 = 100\,\Omega$$

Capacitive reactance,

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi v C}$$
$$= \frac{1}{2 \times \pi \times \frac{50}{\pi} \times 20 \times 10^{-6}}$$
$$= 500\,\Omega$$

Impedance of circuit,

$$Z = \sqrt{R^2 + (X_C - X_L)^2}$$
$$= \sqrt{(300)^2 + (500 - 100)^2}$$
$$= \sqrt{90000 + 16000}$$
$$= \sqrt{250000} = 500\,\Omega$$
$$I_{rms} = \frac{V_{rms}}{Z} = \frac{50}{500} = 0.1\,\text{A}$$

180. An alternating voltage given by $V = 140 \sin 314\,t$ is connected across a pure resistor of $50\,\Omega$. Find:

1. The frequency of the source.
2. The rms current through the resistor.

Ans : **Main 2017, 2010**

1. Given:

$$V = 140 \sin 314t$$

and $R = 50\,\Omega$

Comparing it with,

$$V = V_0 \sin \omega t$$

Here, $\omega = 314$ rad/s

i.e., $2\pi v = 314$

$$v = \frac{314}{2\pi} \approx 50\,\text{Hz}$$

Frequency of AC,

$$v = 50\,\text{Hz}$$

2. As,

$$I_{rms} = \frac{V_{rms}}{R}$$

and $V_{rms} = \frac{V_0}{\sqrt{2}}$

Here, $V_0 = 140\text{V}$

$$V_{rms} = \frac{140}{\sqrt{2}} \times \frac{\sqrt{2}}{\sqrt{2}} = 70\sqrt{2}\ \text{V}$$

Hence, $I_{rms} = \frac{70\sqrt{2}}{R} = \frac{70\sqrt{2}}{50}$

$$= 1.9\ \text{A} \approx 2\ \text{A}$$

181. A circuit is set up by connecting inductance $L = 100\,\text{mH}$, resistor $R = 100\,\Omega$ and a capacitor of reactance $200\,\Omega$ in series. An alternating emf of $150\sqrt{2}\,\text{V}$, $\frac{500}{\pi}$ Hz is applied across this series combination. Calculate the power dissipated in the resistor.

Ans : **SQP 2011**

Given, $L = 100 \times 10^{-3}\,\text{H}$, $R = 100\,\Omega$

$$X_C = 200\,\Omega$$
$$V_{rms} = 150\sqrt{2}\ \text{Volt}$$
$$v = \frac{500}{\pi}\,\text{Hz}$$

Inductive reactance,

$$X_L = \omega L = 2\pi v L$$
$$= 2 \times \pi \times \frac{500}{\pi} \times 100 \times 10^{-3}$$
$$= 100\,\Omega$$

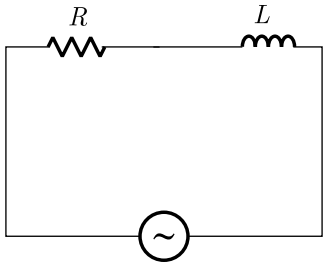
Impedance of circuit,

$$Z = \sqrt{R^2 + (X_C - X_L)^2}$$
$$= \sqrt{(100)^2 + (200 - 100)^2}$$
$$= \sqrt{20000}$$
$$= 100\sqrt{2}$$
$$I_{rms} = \frac{V_{rms}}{Z}$$
$$= \frac{150\sqrt{2}}{100\sqrt{2}} = \frac{3}{2}$$

Power dissipated

$$= (I_{rms})^2\ R$$
$$= \frac{9}{4} \times 100 = 225\,\text{W}$$

182. In the R-L circuit shown in the given figure, the resistance, $R = 30\,\Omega$, reactance, $X_L = 40\,\Omega$ and peak emf, $\varepsilon_0 = 220\,\text{V}$.



Calculate

(i) the impedance Z.

(ii) phase difference between the emf and current.

(iii) the peak current I_0 in circuit.

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Hence, $I_{rms} = \frac{I_0}{\sqrt{2}} = \frac{20}{\sqrt{2}} = 14.14\ A$

169. In an AC circuit, the equation of e.m.f is: $E = 4\cos(100t)$.What is the amplitude of current in an LR-circuit of inductance 0.03 H and resistance 4 Ω?

Ans : SQP 2012, 2010

Equation of e.m.f., $E = 4\cos(100t)$

Inductance, $L = 0.03\ H$

Resistance, $R = 4\ \Omega$

The standard equation of e.m.f. in an AC circuit,

$$E = E_0\cos(\omega t)$$

Comparing the given equation with the standard equation, we get

$$E_0 = 4$$

and $$\omega = 100$$

We also know that impedance of LR-circuit,

$$Z = \sqrt{R^2 + (X_L)^2}$$
$$= \sqrt{R^2 + (\omega L)^2}$$
$$= \sqrt{R^2 + \omega^2 L^2}$$
$$= \sqrt{(4)^2 + [(100)^2 \times (0.03)^2]}$$
$$= \sqrt{16 + 9} = \sqrt{25} = 5\ \Omega$$

Therefore, amplitude of current in the circuit,

$$I_0 = \frac{E_0}{Z} = \frac{4}{5} = 0.8\ A$$

170. A 60 Ω resistor, a 10 H inductor and a 4 μF capacitor are connected in series to AC supply generating and emf $e = 300\sin(500t)$ V. Calculate

(a) impedance of the circuit.

(b) peak value of the current flowing through the circuit.

(c) phase difference between the current and the supply voltage.

Ans : Main 2000

Given,

$$\varepsilon = 300\sin(500t)\ V$$

Total reactance of the circuit is combination of capacitance and inductive reactance.

$$(X_C - X_L) = \left|\frac{1}{\omega_C} - \omega_L\right|$$
$$= \left|\frac{1}{500 \times 4 \times 10^{-6}} - 500 \times 1\right|$$
$$= \left|5 \times 10^2 - 500\right|$$
$$(X_C - X_L) = 0$$

(a) $$Z = \sqrt{R^2 + (X_C - X_L)^2}$$
$$= \sqrt{(60)^2 + 0}$$
$$= 60\ \Omega$$

(b) $$I_0 = \frac{E_0}{Z} = \frac{300}{60} = 5\ A$$

(c) $$\tan\phi = \left|\frac{X_C - X_L}{R}\right| = \frac{0}{60} = 0^\circ$$

171. In a series combination, $R = 300\ \Omega$, $L = 0.9\ H$, $C = 2\ \mu F$, $\omega = 1000\ rad - s^{-1}$.What is the impedance of the LCR-circuit?

Ans : Main 2016

Given,

Resistance, $R = 300\ \Omega$

Inductance, $L = 0.9\ H$

Capacitance, $C = 2\ \mu F = 2 \times 10^{-6}\ F$

Angular velocity, $\omega = 1000\ rad - s^{-1}$

Reactance of inductor,

$$X_L = \omega L = 1000 \times 0.9 = 900\ \Omega$$

and reactance of capacitor,

$$X_C = \frac{1}{\omega C} = \frac{1}{1000 \times (2 \times 10^{-6})}$$
$$= 500\ \Omega$$

Therefore, impedance of LCR-circuit

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$
$$= \sqrt{(300)^2 + (900 - 500)^2}$$
$$= \sqrt{90000 + 160000}$$
$$= \sqrt{250000} = 500\ \Omega$$

172. In a series LCR-circuit, resistance $R = 10\ \Omega$ and the impedance $Z = 20\ \Omega$. What is the phase difference between the current and the voltage?

Ans : SQP 2015, 2010

Given,

Resistance, $R = 10\ \Omega$

Impedance, $Z = 20\ \Omega$

Impedance in the LCR-circuit,

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$
$$20 = \sqrt{(10)^2 + (X_L - X_C)^2}$$
$$400 = 100 + (X_L - X_C)^2$$
$$(X_L - X_C)^2 = 400 - 100 = 300$$
$$X_L - X_C = \sqrt{300} = 10\sqrt{3}$$

We also know that phase difference between current and voltage,

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185. When an alternating emf $e = 310\sin(100\pi t)$ V is applied to a series L-C-R circuit, current flowing through it is $i = 5\sin(100\pi t + \pi/3)$ A.

(a) What is the phase difference between the current and the emf?

(b) Calculate the average power consumed by the circuit.

Ans : **Main 2020, 2012**

Given, $e = 310\sin(100\pi t)$ V ...(1)

and $I = 5\sin\left(100\pi t + \frac{\pi}{3}\right)$ A ...(2)

(a) Comparing Eqs. (1) and (2) with standard equation, the phase difference between emf (e) and current (I) is

$$\Delta\phi = |\phi_1 - \phi_2|$$
$$= \left|0 - \frac{\pi}{3}\right| = \left|-\frac{\pi}{3}\right| = 60^\circ$$

(b) average power consumed,

$$P_{av} = E_{rms} I_{rms} \cos\theta$$
$$= \frac{E_0}{\sqrt{2}} \times \frac{I_0}{\sqrt{2}} \times \cos\phi$$
$$E_0 = \text{peak emf} = 310 \text{ V}$$
$$I_0 = \text{peak current} = 5 \text{ A}$$
$$\cos\phi = \text{power factor} = \cos 60^\circ = \frac{1}{2}$$
$$P_{av} = \frac{310}{\sqrt{2}} \times \frac{5}{\sqrt{2}} \times \frac{1}{2}$$
$$= \frac{1550}{4} = 387.5 \text{ W}$$

186. An alternating emf of frequency 50 Hz is applied to a circuit with a resistor of 20 Ω, an inductor of 100 mH and a capacitor of 30 μF connected in series.

(i) What is the angle by which the current leads or lags the applied emf?

(ii) Represent the voltage and the current in a vector diagram showing the phase angle.

Ans : **Main 2006**

Given, $f = 50$ Hz, $R = 20\,\Omega$,

$$L = 100 \text{ mH} = 100 \times 10^{-3} \text{ H}$$
$$C = 30\,\mu\text{F} = 30 \times 10^{-6} \text{ F}$$

(i) $X_L = 2\pi fL = 2 \times 3.14 \times 50 \times 100 \times 10^{-3}$
$= 31.4\,\Omega$

$$X_C = \frac{1}{2\pi fC}$$
$$= \frac{1}{2 \times 3.14 \times 50 \times 30 \times 10^{-6}}$$
$$= 106.16\,\Omega$$
$$\tan\phi = \frac{X_C - X_L}{R}$$

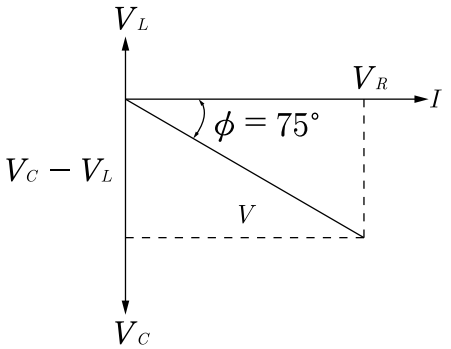
[ϕ = phase difference between current and voltage]

$$= \frac{106.16 - 31.4}{20} = 3.73$$
$$\phi = 75^\circ$$

(ii) As $X_C > X_L$

$V_C > V_L$

Hence, current leads the voltage by angle $\phi = 75^\circ$ as shown.



187. An alternating emf of 220 V is applied to a circuit containing a resistor R having resistance of 160 Ω and a capacitor C in series. The current is found to lead the supply voltage by an angle $\theta = \tan^{-1}\left(\frac{3}{4}\right)$.

(a) Calculate

I. the capacitive reactance

II. impedance of the R-C circuit.

III. current flowing in the circuit.

(b) If the frequency of the applied emf is 50 Hz, what is the value of the capacitance of the capacitor C?

Ans : **Main 2018**

As we know , $\tan\theta = \frac{X_C}{R}$

$$\theta = \tan^{-1}\left(\frac{3}{4}\right)$$
$$\tan\theta = \frac{3}{4}$$
$$\frac{3}{4} = \frac{X_C}{160}$$

(a) I. Capacitive reactance,

$$X_C = 160 \times \frac{3}{4} = 120\,\Omega$$

II. Impedance of the R-C circuit,

$$Z = \sqrt{R^2 + (X_C)^2}$$
$$= \sqrt{(160)^2 + (120)^2}$$
$$= \sqrt{40000} = 200\,\Omega$$

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$$X_L = \omega L = 2\pi fL = 2 \times 3.14 \times \frac{4}{\pi^2} \times 50$$
$$= 127.3\,\Omega$$

Substituting the all values in Eq. (1), we get

$$Z = \sqrt{(100)^2 + (127.3 - 127.3)^2}$$
$$= \sqrt{(100)^2} = 100\,\Omega$$
$$I_{\text{rms}} = \frac{E_{\text{rms}}}{Z} = \frac{220}{100} = 2.2\text{ A}$$

(c) Average power consumed by the circuit

$$= E_{\text{rms}} \times I_{\text{rms}} \times \frac{R}{\sqrt{R^2 + (L\omega - \frac{1}{C\omega})}}$$
$$Z = R = 100\,\Omega$$

So, Power $= E_{\text{rms}} \times I_{\text{rms}} = 220 \times 2.2 = 484$ W

193. An 8 H inductor, a 2 μF capacitor and a 100 Ω resistor are connected in series to an AC supply of 220 V and 50 Hz. Calculate

(a) impedance of the circuit

(b) current flowing through the circuit

(c) phase difference between the current and the supply voltage

(d) average power consumed by the circuit.

Ans : SQP 2018

Given, $L = 8\text{ H},\ C = 2\,\mu\text{F} = 2 \times 10^{-6}\text{ F}$

$R = 100\,\Omega,\ v = 50\text{ Hz},$

$E_{\text{rms}} = 220\text{ V}$

(a) $X_L = \omega L = 2\pi v \times L$

$2 \times 314 \times 50 \times 8 = 2512\,\Omega$

$$X_C = \frac{1}{\omega C}$$
$$= \frac{1}{2 \times 3.14 \times 50 \times 2 \times 10^{-6}}$$
$$= 1592\,\Omega$$

Impedance, $Z = \sqrt{R^2 + (X_L - X_C)^2}$

$$= \sqrt{(100)^2 + (2512 - 1592)^2}$$
$$= 925.41\,\Omega = 925\,\Omega$$

(b) $$I_{\text{rms}} = \frac{E_{\text{rms}}}{Z} = \frac{220}{925} = 0.238\text{ A}$$

(c) Phase difference

$$\phi = \tan^{-1}\frac{(X_L - X_C)}{R}$$
$$= \tan^{-1}\frac{(2512 - 1529)}{100}$$
$$= \tan^{-1}(9.2) = 83^\circ 7$$

(d) Average power

$$(P) = I_{\text{rms}} E_{\text{rms}} \cos\theta$$
$$= 0.238 \times 220 \times \cos 83^\circ 7'$$
$$= 0.23 \times 220 \times 0.119$$
$$= 6.23\text{ W}$$

194. A coil having self-inductance of 0.7 H and resistance of 165 Ω is connected to an AC source of 275 V, 50 Hz. If $\pi = \frac{22}{7}$, then calculate

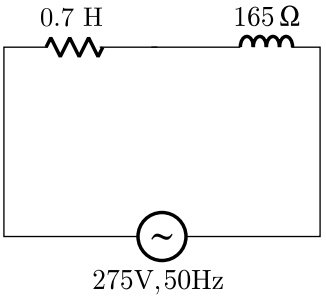
(a) reactance of the coil

(b) impedance of the coil

(c) current flowing through the coil.

Ans : Main 2016, 2011

According to the question,we can draw the following diagram



(a) Reactance of the coil is

$$X_L = \omega L$$
$$= 2\pi fL = 2 \times \frac{22}{7} \times 50 \times 0.7$$
$$= 220\,\Omega$$

(b) Impedance of the coil,

$$Z = \sqrt{X_L^2 + R^2}$$
$$= \sqrt{(\omega L)^2 + R^2}$$
$$= \sqrt{(2\pi \times 50 \times 0.7)^2 + (165)^2}$$
$$= \sqrt{48400 + 27225}$$
$$= \sqrt{75625} = 275$$

(c) Current flowing through the coil,

$$V = IR$$
$$I = \frac{V}{R}$$

(R = resistance of circuit and V = voltage applied)

$$I = \frac{275}{275}$$
$$I = 1\text{ A}$$

(a) Impedance, $Z = \sqrt{R^2 + X_C^2}$

$$Z = \sqrt{(200)^2 + \left(\frac{1}{C\omega}\right)}$$

$$= \sqrt{(200)^2 \frac{1}{\left(\frac{50}{\pi} \times 10^{-6} \times 100\,\pi\right)}}$$

$$[\omega = 2\pi n = 2\pi \times 50 = 100\,\pi]$$

$$= \sqrt{(200)^2 + (200)^2}$$

$$= 200\sqrt{2}\,\Omega$$

(b) Phase angle (ϕ)

$$\cos\phi = \frac{R}{\sqrt{R^2 + \left(\frac{1}{\omega C}\right)^2}} = \frac{R}{Z}$$

$$= \frac{200}{200\sqrt{2}} = \frac{1}{\sqrt{2}}$$

$$\phi = 45^\circ$$

(c) Voltage across resistors,

$$V_R = I_{\text{rms}} R$$

$$E_{\text{rms}} = \frac{E_0}{\sqrt{2}} \Rightarrow \frac{100}{\sqrt{2}} \Rightarrow 50\sqrt{2}$$

$$= \frac{50\sqrt{2} \times 200}{200\sqrt{2}} \left[I_{\text{rms}} = \frac{E_{\text{rms}}}{Z}\right]$$

$$= 50\,V$$

191. An AC generator generating an emf of $\varepsilon = 300\sin(100\pi t)$ V is connected to a series combination of 16 μF capacitor, 1 H inductor and 100 Ω resistor. Calculate

(a) impedance of the circuit at the given frequency

(b) resonant frequency f_0.

(c) power factor at resonant frequency f_0.

Ans : **Main 2018**

The equation of emf is given by

$$\varepsilon = 300\sin(100\pi t)\text{ V}$$

The standard equation of emf,

$$\varepsilon = \varepsilon_0 \sin\omega t$$

$$\omega = 100\pi$$

$$2\pi f = 100\pi \qquad [\omega = 2\pi f]$$

(a) Impedance of the circuit (L - C - R),

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$$= \sqrt{R^2 + \left(2\pi fL - \frac{1}{2\pi fC}\right)^2}$$

$$= \sqrt{100^2 + \left(100\pi \times 1 - \frac{1}{100\pi \times 16 \times 10^{-6}}\right)^2}$$

$$= \sqrt{100^2 + (314 - 199)^2}$$

$$= \sqrt{100^2 + 115^2} = 152.39\,\Omega$$

(b) Resonant frequency,

$$f_0 = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{1 \times 16 \times 10^{-6}}}$$

$$= \frac{1}{2\pi \times 4 \times 10^{-3}} = 39.8\text{ Hz}$$

(c) Power factor,

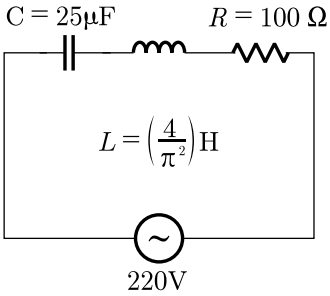
$$\cos\phi = \frac{R}{Z}$$

At resonant frequency,

$$R = Z$$

$$\cos\phi = 1$$

192. Figure below shows a capacitor C, an inductor L and a resistor R connected in series to an AC supply of 220 V.



Calculate

(a) the resonant frequency of the given L-C-R circuit.

(b) current flowing through the circuit.

(c) average power consumed by the circuit.

Ans : **Main 2015, 2012**

Given, $E_{\text{rms}} = 220$ V, $C = 25\,\mu\text{F} = 25 \times 10^{-6}$ F

$$L = \frac{4}{\pi^2}\text{H},\ R = 100\,\Omega$$

(a) Resonant frequency is given by

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

$$= \frac{1}{2 \times 3.14 \times \sqrt{\frac{4}{\pi^2} \times 25 \times 10^{-6}}}$$

$$= \frac{1}{2 \times 3.14 \times \frac{2}{3.14} \times 5 \times 10^{-3}}$$

$$= 50\text{ Hz}$$

(b) Impedance of the circuit is given by

$$Z = \sqrt{R^2 + (X_L - X_C)^2} \qquad ...(1)$$

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi fC}$$

$$= \frac{1}{2 \times 3.14 \times 50 \times 25 \times 10^{-6}}$$

$$= 127.3\,\Omega$$

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III. We have, $Z = \frac{V}{i}$

Current flowing in the circuit,

$$i = \frac{V}{Z} = \frac{220}{200} = 1.1\,\text{A}$$

(b) $$X_C = \frac{1}{2\pi f C}$$

$$120 = \frac{1}{2\pi \times 50 \times C}$$

$$C = \frac{1}{2\pi \times 50 \times 120}$$

Capacitance, $$C = 2.65 \times 10^{-5}\,\text{F}$$

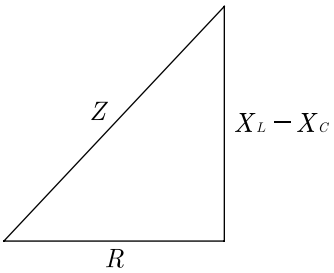
188. A $50\,\mu\text{F}$ capacitor, a $30\,\Omega$ resistor and a $0.7\,\text{H}$ inductor are connected in series to an AC supply which generate an emf e given by, $e = 300\sin(200t)\,\text{V}$.Calculate peak value of the current flowing through the circuit.

Ans : **Main 2012, 2010**

Given,

$$C = 50\,\mu\text{F},\ R = 30\,\Omega,\ L = 0.7\,\text{H}$$

$$e = 300\sin(200t),$$



By comparing with $e = e_0 \sin\omega t$

$$\omega = 200\,\text{rad/s},\ e_0 = 300\,\text{V}$$

Impedance

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$$= \sqrt{(30)^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

$$= \sqrt{(30)^2 + \left(200 \times 0.7 - \frac{10^6}{200 \times 50}\right)^2}$$

$$= \sqrt{900 + (140 - 100)^2}$$

$$Z = 50\,\Omega$$

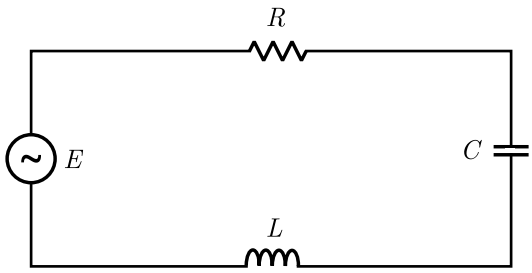
I_0 = Peak value of current

$$= \frac{\text{Peak value of voltage}}{\text{Impedance}}$$

$$= \frac{e_0}{Z} = \frac{300}{50} = 6\,\text{A}$$

189. The figure shows a series LCR circuit connected to a variable frequency 200 V source with $L = 50\,\text{mH}$, $C = 80\,\mu\text{F}$ and $R = 40\,\Omega$.

1. The source frequency which derives the circuit in resonance.
2. The quality factor Q of the circuit.



Ans : **Comp 2015**

Given, $$L = 50\,\text{mH} = 50 \times 10^{-3}\,\text{H}$$

$$C = 80\,\mu\text{F} = 80 \times 10^{-6}\,\text{F}$$

$$R = 40\,\Omega$$

$$V = 200\,\text{Volt}$$

1. In the LCR, circuit the resonant angular frequency is given by,

$$\omega_0 = 2\pi v$$

$$v = \frac{\omega}{2\pi}$$

$$v = \frac{500}{2\pi}$$

$$= \frac{250}{\pi}$$

$$= 79.61 \approx 80\,\text{Hz}$$

2. Quality factor, $Q = \frac{\omega_0 L}{R}$

$$= \frac{500 \times 50 \times 10^{-3}}{40}$$

$$= 0.625$$

190. A series CR circuit with $R = 200\,\Omega$ and $C = (50/\pi)\,\mu\text{F}$ is connected across an ac source of peak voltage $\varepsilon_n = 100\,V$ and frequency $v = 50\,\text{Hz}$. Calculate (a) impedance of the circuit (Z). (b) phase angle (ϕ) and (c) voltage across the resistor.

Ans : **Main 2023**

In the given circuit,

$$R = 200\,\Omega$$

$$C = \left(\frac{50}{\pi}\right)\mu F$$

Peak voltage, $$E_0 = 100\,V$$

Frequency, $$v = 50\,\text{Hz}$$

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195. An alternating emf of 110 V is applied to a circuit containing a resistance R of 80 Ω and an inductor L in series. The current is found to lag behind the supply voltage by an angle, $\theta = \tan^{-1}(3/4)$. Then, find the

(i) inductive reactance.

(ii) impedance of the circuit.

(iii) current flowing in the circuit.

(iv) if the inductor has coefficient of self-inductance of 0.1 H, what is the frequency of the applied emf?

Ans : **Main 2014, 2011**

We have to apply formula to

$$\tan\phi = \frac{X_L}{R}$$

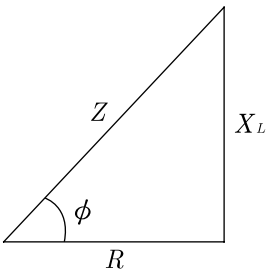
Net impedance can be calculated by

$$Z = \sqrt{X_L^2 + R^2}$$

(i) We can write

$$\tan\phi = \frac{X_L}{R} = \frac{3}{4}$$

[given in the question]



$$\frac{X_L}{R} = \frac{3}{4}$$

$$R = 80\,\Omega$$

$$X_L = \frac{3}{4} \times R = \frac{3}{4} \times 80\,\Omega = 60\,\Omega$$

(ii) Impedance, $Z = \sqrt{X_L^2 + R^2}$

$$= \sqrt{(60)^2 + (80)^2} = 100\,\Omega$$

(iii) Current, $I_{\text{rms}} = \frac{V_{\text{rms}}}{Z} = \frac{110}{100} = 1.1\text{ A}$

(iv) We know that,

$$X_L = \omega L$$

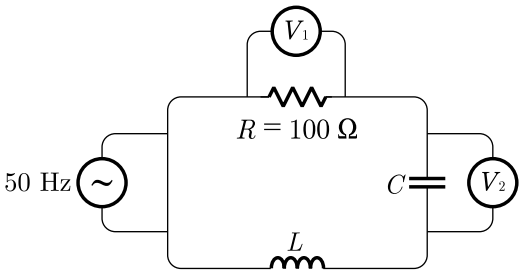
$$60 = (0.1) \times \omega \qquad [L = 0.1\text{ H}]$$

$$\omega = 600\text{ rad/s}$$

$$2\pi f = 600\text{ rad/s}$$

$$f = 95.5\text{ Hz} = 96\text{ Hz}$$

196. Figure below shows a series L-C-R circuit connected to an AC source which generates an alternating emf of frequency of 50 Hz. The reading of voltmeters V_1 and V_2 are 80 V and 60 V, respectively.



Find

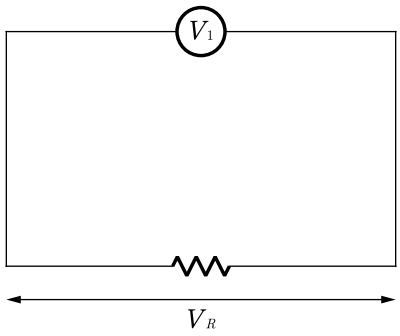
(a) the current in the circuit.

(b) the capacitance C of the capacitor.

Ans : **Main 2013**

Apply $I = V/R$ to obtain current through the resistor. At resonance, impedance of capacitor and inductor can be equated and cancelled.

Now according to the question,



(a) Electric current in the circuit

$$I = \frac{V_R}{R} = \frac{V_1}{R}$$

$$= \frac{80}{100} = 0.8\text{ A}$$

(b) Current through the capacitor, I_C is equal to the current through resistor as they are in series

$$I_R = I_C$$

$$0.8 = \frac{V_C}{X_C}$$

$$V_C = V_L$$

$$(0.8) \times X_C = (0.8)\left(\frac{1}{\omega C}\right)$$

$$\frac{1}{C} = \frac{V_2 \times \omega}{0.8}$$

$$= \frac{60 \times 2\pi f}{0.8} \qquad [V_L = V_C]$$

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CHAPTER 8

Electromagnetic Waves

SUMMARY

1. DISPLACEMENT CURRENT

Ampere's circuital law for conduction current during charging of a capacitor was found inconsistent therefore Maxwell modified Ampere's circuital law by introducing displacement current. It is given by

$$I_d = \varepsilon_0 \frac{d\phi_E}{dt}$$

Modified Ampere's circuital law is,

$$\oint \vec{B}.d\vec{l} = \mu_0\left(I + \varepsilon_0 \frac{d\phi_E}{dt}\right)$$

Where, ϕ_E = electric flux

2. CHARACTERISTICS OF ELECTROMAGNETIC WAVES

Characteristics of electromagnetic wave are as follows::

1. Speed of electromagnetic wave,
$$c = \frac{E_0}{B_0} = \frac{c}{\sqrt{\mu_0 \varepsilon_0}}$$
2. The speed of electromagnetic waves in a material medium is given by,
$$v = \frac{1}{\sqrt{\mu\varepsilon}} = \frac{c}{\sqrt{\mu_r \varepsilon_r}} = \frac{c}{n}$$
where, n is the refractive index.
3. Energy associated with an electromagnetic wave is,
$$U = \frac{1}{2}\varepsilon_0 E^2 + \frac{B^2}{2\mu_0}$$
4. Linear momentum delivered to the surface, $p = \frac{U}{c}$.
where, U = total energy transmitted by electromagnetic waves and c = speed of electromagnetic wave.

3. ELECTROMAGNETIC SPECTRUM

The electromagnetic waves have a continuous wavelength starting from short gamma rays to long radio-waves. The orderly distribution of wavelength of EM waves is called the electromagnetic spectrum. The complete spectrum is given in the following table.

	Name	Wavelength Range (m)	Frequency Range (Hz)
1.	Gamma rays	$10^{-13} - 10^{-10}$	$3 \times 10^{21} - 3 \times 10^{18}$
2.	X-rays	$10^{-10} - 10^{-8}$	$3 \times 10^{18} - 3 \times 10^{16}$
3.	Ultraviolet rays	$10^{-8} - 4 \times 10^{-7}$	$3 \times 10^{16} - 7.5 \times 10^{14}$
4.	Visible light	$4 \times 10^{-7} - 7.5 \times 10^{-7}$	$7.5 \times 10^{14} - 4 \times 10^{14}$
5.	Infrared light	$7.5 \times 10^{-7} - 10^{-3}$	$4 \times 10^{14} - 8 \times 10^{14}$
6.	Microwaves	$10^{-3} - 10^{-1}$	$3 \times 10^{11} - 10^{10}$
7.	Radio waves	$10^{-1} - 10^{4}$	$10^{10} - 3 \times 10^{4}$

4. ELEMENTARY FACTS ABOUT THE USES OF ELECTROMAGNETIC WAVES

Radio Waves

1. In radio and TV communication.
2. In astronomical field.

Microwaves

1. In RADAR communication.
2. For cooking purpose.
3. In analysis of molecular and atomic structure.

Infrared Waves

1. In knowing molecular structure.
2. In remote control of TV, VCR, etc.

Ultraviolet Rays

1. Used in burglar alarm.
2. To kill germs in water-purifiers.

X-rays

1. In medical diagnosis as they pass through the muscles not through the bones.
2. In detecting faults, cracks, etc., in metal products.

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Since, inductive reactance,

$$X_L = \omega L$$

$$X_L = 1000 \times 100 \times 10^{-3}$$

$$X_L = 100\,\Omega$$

So, we can see that $X_C > X_L$, $\tan\phi$ is negative.

Hence, the voltage lags behind the current by a phase angle ϕ. The AC circuit is capacitance dominated circuit.

Since, phase difference,

$$\tan\phi = \frac{X_L - X_C}{R}$$

$$\tan\phi = \frac{100 - 500}{400}$$

$$\tan\phi = \frac{-400}{400}$$

$$\tan\phi = -1$$

$$\tan\phi = -\tan\left(\frac{\pi}{4}\right)$$

$$\phi = -\frac{\pi}{4}$$

This is the required value of the phase difference between the current and the voltage in the given series LCR circuit.

(ii) Suppose, new capacitance of the circuit is C'.

Thus, to have power factor unity

$$\cos\phi' = 1 = \frac{R}{\sqrt{R^2 + (X_L - X'_C)^2}}$$

$$R^2 = R^2 + (X_L - X'_C)^2$$

$$X_L = X'_C \text{ or } \omega L = \frac{1}{\omega C'}$$

$$\omega^2 = \frac{1}{LC'}$$

$$(1000)^2 = \frac{1}{LC'} \qquad (\text{Since, } \omega = 1000)$$

$$C' = \frac{1}{L \times 10^6}$$

$$= \frac{1}{100 \times 10^{-3} \times 10^6}$$

$$= \frac{10}{10^6} = \frac{1}{10^5} = 10^{-5}$$

$$C' = 10^{-5}\,\text{F}$$

$$= 10 \times 10^{-6}\,\text{F}$$

$$= 10\mu\text{F}$$

As, $C' > C$. Hence we have to add an additional capacitor of capacitance 8μF $(10\mu\text{F} = 2\mu\text{F})$ in parallel with previous capacitor.

CASE BASED QUESTIONS

199. Monika and her friends visited an exhibition. The policeman asked them to pass through a metal detector Monika's friends were initially scared of it. Monika however, explained to them the purpose and working of the metal detector.

(i) On what principle does a metal detector work?

(ii) Why does the detector emit sound when a person carrying any metallic object walks through it?

Ans : 2015

(i) Metal detector works on the principle of resonance in AC circuits.

(ii) When a person carrying any metallic object walks through the gate of a metal detector, the impedance of the circuit changes, resulting in significant change in current in the circuit that causes a sound to be emitted as an alarm.

200. Deepak had a high tension tower erected on his farm land. He kept complaining to the authorities to remove it as it was occupying a large portion of his land. His uncle, who was a teacher, explained to him the need for erecting these towers for efficient transmission of power. As Deepak its realised significance, he stopped complaining, Answer the following questions.

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(i) Why is it necessary to transport power at high voltage?

(ii) A low power factor implies large power loss. Explain.

$$= \frac{600 \times 2\pi \times 50}{8}$$

$$C = \frac{8}{6 \times 5 \times 2\pi \times 10^3}$$

$$C = 42.46\,\mu\text{F}$$

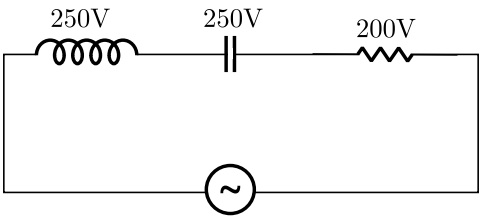
197. A series LCR circuit is connected to an AC source (200 V, 50 Hz). The voltages across the resistor, capacitor and inductor are respectively 200 V, 250 V and 250 V.

(i) The algebraic sum of the voltage across the three elements is greater than the voltage of the source. How is this paradox resolved?

(ii) Given the value of the resistance of R is $40\,\Omega$, calculate the current in the circuit.

Ans : **Comp 2020, 2014**

(i) From given parameters $V_R = 200$ V, $V_L = 250$ V and $V_C = 250$ V



V_{eff} should be given as

$$V_{eff} = V_R + V_L + V_C$$

$$= 200\text{ V} + 250\text{ V} + 250\text{ V}$$

$$= 700\text{ Volt}$$

However, $V_{eff} > 200$ V of the AC source.

This paradox can be solved only by using phaser diagram, as given below.

$$V_{eff} = \sqrt{V_R^2 + (V_L - V_C)^2}$$

Since, $V_L = V_C$

so, $V_R = 200$ Volt

(ii) Given, $R = 40\,\Omega$, so current in the LCR circuit.

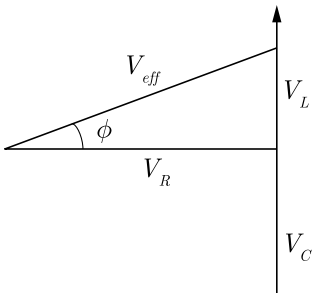
$$I_{eff} = \frac{V_{eff}}{R}$$

$$X_L = X_C$$

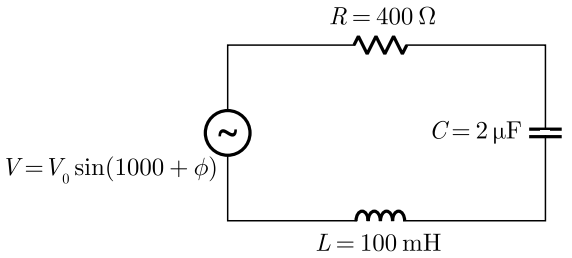
or $$Z = R$$

$$= \frac{200}{40}$$

$$= 5\text{ A}$$



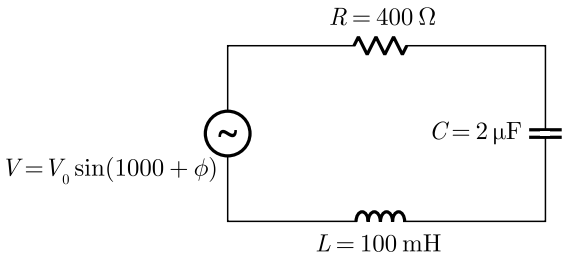
198. (i) Determine the value of phase difference between the current and the voltage in the given series LCR circuit.



(ii) Calculate the value of additional capacitor which may be joined suitably to the capacitor C that would make the power factor of the circuit unity.

Ans : **SQP 2020**

(i) Consider the given figure



Since, the alternating emf in the above LCR series circuit would be represented by

$$V = V_0 \sin(1000t + \phi)$$

$$\omega = 1000\text{ Hz}$$

Given, $R = 400\Omega$, $C = 2\mu\text{F}$, $L = 100\,\text{mH}$

Hence, capacitive reactance,

$$X_C = \frac{1}{\omega C}$$

$$X_C = \frac{1}{1000 \times 2 \times 10^{-6}}$$

$$X_C = \frac{10^3}{2} = 500\,\Omega$$

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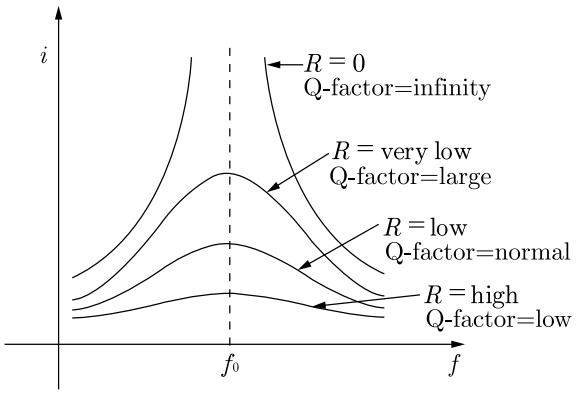
203. Quality Factor defines the $i-f$ curve at resonance. The characteristic of a series resonant circuit is determined by the quality factor (Q – factor).

If resonance in an L-C-R circuit is less sharp (see graph) not only the maximum current in the circuit is less, the circuit is closed to resonance for a larger range of frequency ($\Delta\omega$) and tuning of circuit is difficult. So, if resonance is more sharp, circuit is more selective for a particular frequency and current in the circuit is large.



Resonance curve

The ratio of resonant frequency to band width which is responsible for sharpness of resonance is called Q-factor or quality factor of the circuit. It is represented as

$$Q\text{-factor} = \frac{V_L}{V_R} = \frac{V_C}{V_R} = \frac{1}{R}\sqrt{\frac{L}{C}}$$

$$= \frac{\omega_0}{2\Delta\omega} = \frac{1}{\omega_0 CR} = \frac{\omega_0 L}{R}$$

[ω_0 = resonant frequency]

(i) What is the other name of quality factor?

(ii) What is the voltage across the capacitor when the source voltage is 100 V and Q-factor is 10.

(iii) Find the Q-factor when the voltage across the capacitor is 1000 V and the source voltage is 100 V.

(iv) What happens to the voltage across the capacitor when the Q-factor increases?

(v) What happens to the voltage across the inductor when the Q-factor decreases?

Ans :

(i) Quality factor is also known as voltage magnification because the voltage across the capacitor or inductor in resonance condition is Equal to Q-times the source voltage.

(ii) Voltage across the capacitor in resonance condition is equal to Q-times the source voltage.

$$Q = V_C / V_S$$

$$10 = \frac{V_C}{100}$$

$$V_C = 1000 \text{ V}$$

(iii) $$Q = \frac{V_C}{V_S}$$

$$= \frac{1000}{100} = 10 \text{ V}$$

(iv) As, we know the voltage across the capacitor in resonance condition is Equal to Q-times the source voltage. Hence, as the Q-factor increases, the voltage across the capacitor also increases.

(v) When the Q-factor decrease, the voltage across the inductor also decreases because the voltage across the inductor in resonance condition is equal to Q-times the source voltage.

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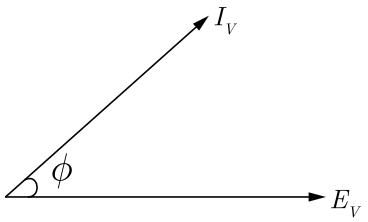
Ans : **2015**

(i) Power loss in the form of heating through wires is given by I^2R.



If the power is transmitted at high voltage then low current flows through wires and hence there is less power loss $P = VI$.

If V increases, I decreases.

(ii) In AC $P_{av} = E_v I_v \cos\phi$

Where $\cos\phi$ is power factor and ϕ is the phase between E_v and I_v.

Smaller value of $\cos\phi$ will result in higher value of current which will result in more power loss. Hence, low power factor implies large power loss.

201. Rakesh is a student of class x in a school near his village. His uncle gifted him a bicycle with a dynamo fitted in it. He was thrilled to find that while cycling during night, he could light the bulb and see the objects on the road clearly. He, however, did not know how this device works. He asked this question to his teacher. The teacher considered it an opportunity and explained the working of dynamo to the whole class.

(i) What is the principle of a dynamo?

(ii) Explain the working of dynamo

Ans : **2015**

(i) It is based on Faraday law of electromagnetic induction.

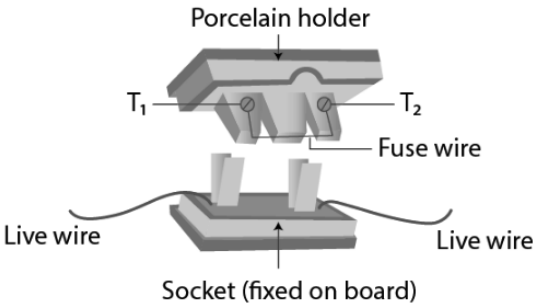
(ii) The changing magnetic flux through the coil provides the necessarily induced emf across the ends of the coil.

Working The coil (called armature) is mechanically rotated in the uniform magnetic field by some external means the rotation of the coil causes the magnetic flux through it to change, so an emf is induced in the coil. The ends of the coil are connected to an external circuit by means of slip rings and brushes.

When a coil of N turns, each of area A rotates in uniform magnetic field $\vec{B}$, the magnitude of induced emf can be given as

$$E = NBA\omega \sin\omega t$$

202. One morning an old man walked bare-foot to replace the fuse wire in kit kat fitted with the power supply mains for his house. Suddenly he screamed and collapsed on the floor. His wife cried loudly for help. His neighbour's son Vishal heard the cries and rushed to the place with shoes on. He took a wooden baton and used it to switch off the main supply.



(i) What is the voltage and frequency of mains supply in India?

(ii) These days most of the electrical devices we use require AC voltage, Why?

(iii) Can a transformer be used to step up DC voltage?

Ans : **2015**

(i) In most generators, the coil is held stationary and electromagnets are rotated at 50 rev/sec, so the frequency of the current is 50 Hz and voltage supply to the consumer is at 220 V.

(ii) (a) AC supply can be stopped up/stopped down.

(b) It can be converted into DC by using full wave rectifiers.

(c) Power loss in transmission line is minimum.

(iii) No, because induced emf in the secondary coil of the transformed is only due to time rate of change of magnetic flux.

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Y-rays

1. As food preservation.
2. In radiotherapy.

****

OBJECTIVE QUESTIONS

1. Which is the most harmful radiation entering the atmosphere of earth from outer space?

(a) X-rays (b) Visible rays

(c) Gamma radiations (d) Radio waves

Ans : **Main 2022 Sem-I**

Gamma radiations are the most harmful because they have very high energy and strong penetrating power. They can damage living cells and tissues, causing serious health effects. Most gamma rays from outer space are absorbed by Earth's atmosphere, protecting life on Earth.

Thus (c) is correct option.

2. Radio-waves and gamma waves are both transverse in nature and electromagnetic in character and have the same speed in vacuum. In what respects, are they different?

(a) Frequency (b) Wavelength

(c) Both (a) and (b) (d) None of these

Ans : **Main 2022 Sem-I**

The radio-waves have atomic origin, while the gamma rays are of nuclear origin. Further, owing to their very small wavelength, gamma rays are highly penetrating in comparison to radio-waves.

Thus (c) is correct option.

3. The frequency of X-rays is

(a) 10^{12} Hz (b) 10^{14} H_z

(c) 10^{16} Hz (d) 10^{18} Hz

Ans : **SQP 2012**

The range of frequency of X-rays is from 10^{17} to 10^{19} Hz. Therefore frequency of X-rays is 10^{18} Hz.

Thus (d) is correct option.

4. Which one of the following travels with the speed of light in vacuum?

(a) Alpha rays (b) Beta rays

(c) Gamma rays (d) Ions

Ans : **Main 2022 Sem-I**

Gamma rays are electromagnetic waves, and all electromagnetic waves travel with the speed of light in vacuum. Alpha rays, beta rays, and ions are particles with mass, so they cannot travel at the speed of light.

Thus (c) is correct option.

5. Which electromagnetic radiation has wavelength greater than that of X-rays and smaller than that of visible light?

(a) Radio waves (b) Microwaves

(c) Infrared rays (d) Ultraviolet rays

Ans : **Main 2022 Sem-I**

In the electromagnetic spectrum, ultraviolet rays have wavelengths greater than X-rays but smaller than visible light. Their wavelength lies between visible light and X-rays, making them more energetic than visible light but less energetic than X-rays.

Thus (d) is correct option.

6. Which of the following have minimum wavelength?

(a) γ-rays (b) X-rays

(c) cosmic rays (d) ultra-violet rays

Ans : **Comp 2010, 2007**

The range of wavelengths of γ-rays is 10^{13} to 10^{-10} m; X-rays 10^{-10} to 10^{-8} m; cosmic rays less than 10^{-12} m and ultra-violet rays 10^{-8} to 4×10^{-7} m. Therefore cosmic rays have minimum wavelength.

Thus (c) is correct option.

7. Which of the following electromagnetic waves have the smallest wavelength?

(a) γ-rays (b) X-rays

(c) UV waves (d) infra-red rays

Ans : **SQP 2002**

The range of wavelengths of γ-rays is 10^{-13} to 10^{-10} m; X-rays 10^{10} to 10^{-8} m; UV waves 10^{-8} to 4×10^{-7} m and infra-red rays 8×10^{-7} to 4×10^{-3} m. Therefore, γ-rays have the smallest wavelength.

8. Which of the following waves have maximum wavelength?

(a) X-rays (b) IR-rays

(c) UV-rays (d) radio-waves

Ans : **Main 2017**

The range of wavelengths of X-rays is 10^{-10} to 10^{-8} m; IR-rays 8×10^{-7} to 4×10^{-3} m; UV-rays 10^{-8} to 4×10^{-7} m and radio-waves greater than 10^{-1} m. Therefore radio-waves have maximum wavelength.

Thus (d) is correct option.

NODIA

24. The unit of ratio of magnetic field, B and electrical field, $E\left(\frac{B}{E}\right)$ is

(a) ms^{-1} (b) sm^{-1}

(c) ms (d) m^{-2}

Ans : **Main 2017**

The speed of electromagnetic wave is given by,

$$c = \frac{E}{B}$$

where, E = Electric field

B = Magnetic field

c = velocity of light

Hence, $$\frac{B}{E} = \frac{1}{c} = \frac{1}{\frac{m}{sec}} = sm^{-1}$$

Thus (b) is correct option.

25. The idea of displacement current was introduced by

(a) Hertz (b) Ampere

(c) Maxwell (d) Farad

Ans : **SQP 2013**

The idea of displacement current was introduced by James Clerk Maxwell. He included displacement current in Ampere's law to explain how changing electric fields can produce magnetic fields. This concept helped in the development of electromagnetic wave theory.

Thus (c) is correct option.

26. The waves which can not travel in vacuum are

(a) X-rays

(b) radio-waves

(c) infrasonic waves

(d) ultra-violet waves

Ans : **Main 2001**

The electromagnetic waves travel in vacuum as well as in a medium, while longitudinal waves need a medium to travel. Since X-rays, radio-waves and ultra-violet waves are electromagnetic waves while infrasonic waves are longitudinal waves, therefore infrasonic waves can not travel in vacuum.

Thus (c) is correct option.

27. Which of the following is/are not electromagnetic waves?

(a) β-rays (b) X-rays

(c) cosmic rays (d) both a and b

Ans : **SQP 2012**

β-rays are stream of high energy electrons produced from the nucleus of a radioactive element after decay.

And cosmic rays come from the other space having high energy charged particles like α-particles, protons etc.

Therefore, β-rays and cosmic rays are not electromagnetic waves.

Thus (d) is correct option.

28. Which of the following radiations have the least wavelength?

(a) X-rays (b) γ-rays

(c) β-rays (d) α-rays

Ans : **Main 2013**

X-rays and γ-rays are electromagnetic waves having range of wavelength 10^{-10} to 10^{-8} m and 10^{-13} to 10^{-10} m respectively. And α-rays and β-rays are of material nature having large wavelength as compared to X-ray and γ-rays which are electromagnetic in nature. Therefore γ -rays have the least wavelength.

Thus (b) is correct option.

29. An electromagnetic wave passing through vacuum is described by the equations: $E = E_0 \sin(kx - \omega t)$ and $B = B_0 \sin(kx - \omega t)$. Then

(a) $E_0 k = B_0 \omega$ (b) $E_0 B_0 = \omega k$

(c) $E_0 \omega = B_0 k$ (d) $E_0 = B_0$

Ans : **SQP 2024, 2009**

Equations of an electromagnetic wave,

$$E = E_0 \sin(kx - \omega t)$$

and $$B = B_0 \sin(kx - \omega t)$$

Velocity of light,

$$c = \nu\lambda = \frac{\omega}{2\pi}\lambda = \frac{\omega}{k} \quad (\text{where, } k = \frac{2\pi}{\lambda})$$

We also know that electric field,

$$E_0 = c \times B_0 = \frac{\omega}{k} \times B_0$$

$$E_0 k = B_0 \omega$$

Thus (a) is correct option.

30. An electromagnetic wave of frequency 3 MHz passes from vacuum into a medium with dielectric constant $k = 4$. Then

(a) both wavelength and frequency remain unchanged.

(b) wavelength is doubled and frequency becomes half.

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(c) Microwaves

(d) Light

Ans : **Main 2022 Sem-I**

Among infrared radiations, microwaves, visible light, and ultraviolet radiations, ultraviolet rays have the highest frequency. In the electromagnetic spectrum, frequency increases from microwaves → infrared → visible light → ultraviolet rays. Hence, ultraviolet radiations possess maximum frequency.

Thus (b) is correct option.

18. Which one of the following is used to detect infrared radiations?

(a) Photocell

(b) Fluorescent screen

(c) Ionisation chamber

(d) Thermopile

Ans : **Main 2022 Sem-I**

A thermopile is used to detect infrared radiations because infrared rays produce a heating effect. A thermopile measures this heat energy and converts it into an electrical signal. Therefore, it is commonly used for detecting infrared radiations.

Thus (d) is correct option.

19. Which one of the following is used to study crystal structure of a crystalline salt?

(a) UV-rays (b) X-rays

(c) Microwaves (d) Radiowaves

Ans : **Main 2022 Sem-I**

X-rays are used to study the crystal structure of crystalline salts because their wavelength is comparable to the spacing between atoms in a crystal. X-ray diffraction helps determine the arrangement of atoms and molecules inside the crystal structure.

Thus (b) is correct option.

20. The phase difference between electric and magnetic fields in an electromagnetic wave is

(a) 0° (b) $\frac{\pi}{2}$

(c) π (d) anything

Ans : **SQP 2009, 2006**

In the electromagnetic waves the variations in electric and magnetic fields are in same phase i.e. The phase difference between electric and magnetic field in an electromagnetic wave is 0°. Because both $\vec{E}$ and $\vec{B}$ attain their maximum and minimum value simultaneously.

Thus (a) is correct option.

NODIA

21. The Maxwell's equations describe the fundamental laws of

(a) electricity (b) magnetism

(c) mechanics (d) both (a) and (b)

Ans : **Main 2010**

The Maxwell's equations are as fundamental equations to electromagnetism as Newton's laws are for the study of the mechanics. These equations describe the fundamental laws of electricity as well as magnetism and also predict the existence of electromagnetic waves. Thus (d) is correct option.

22. $\vec{E}$ and $\vec{B}$ represent the electric and the magnetic field of an electromagnetic wave respectively. The direction of propagation of the wave is along

(a) $\vec{B}$ (b) $\vec{E}$

(c) $\vec{E} \times \vec{B}$ (d) $\vec{B} \times \vec{E}$

Ans : **Main 2023, 2017**

The electric and magnetic field of an electromagnetic wave are perpendicular to each other and their direction of propagation is perpendicular to both the electric and magnetic fields.

If $\vec{E}$ and $\vec{B}$ represent electric and magnetic field vectors of electromagnetic wave, then the direction of propagation of electromagnetic wave is along the direction of vector $\vec{E} \times \vec{B}$.

Thus (c) is correct option.

23. The direction of transmission of electromagnetic wave is

(a) Parallel to $\vec{E}$

(b) Parallel to $\vec{B}$

(c) Parallel to $\vec{B} \times \vec{E}$

(d) Parallel to $\vec{E} \times \vec{B}$

Ans : **Main 2024**

An electromagnetic wave consists of electric and magnetic field oscillating sinusoidally both in time and space. The two fields are perpendicular to each other as well as to the direction of propagation of the wave. Hence the direction of propagation of electromagnetic wave is parallel to $\vec{E} \times \vec{B}$.

Thus (d) is correct option.

9. Which scientist experimentally proved the existence of electromagnetic waves?

(a) Marconi

(b) Heinrich Rudolf Hertz

(c) James Clerk Maxwell

(d) Jagdish Chander Bose

Ans : **Main 2015**

Heinrich Rudolf Hertz was the first scientist to produce and detect the existence of electromagnetic waves experimentally in 1887.

Thus (b) is correct option.

10. The displacement current arises when electric field in a region

(a) increases with time

(b) decreases with time

(c) attains a constant value

(d) both (a) and (b)

Ans : **Main 2007, 2002**

Displacement current arises when electric field in a region changes with time i.e., it increases or decreases.

Thus (d) is correct option.

11. According to the Maxwell's displacement current law, a changing electric field is source of

(a) an e.m.f. (b) magnetic field

(c) pressure gradient (d) all of these

Ans : **Main 2006**

We know according to the Maxwell's displacement current law that a changing electric field is a source of magnetic field.

Thus (b) is correct option.

12. Comic rays are

(a) high energy radiations

(b) low energy radiations

(c) ultra high energy radiations

(d) very low energy radiations

Ans : **SQP 2025**

The cosmic rays are high energy radiations consisting of mainly protons, electrons and some other atomic nuclei.

Thus (a) is correct option.

13. Which of the following rays are not electromagnetic waves ?

(a) γ-rays (b) β-rays

(c) X-rays (d) heat rays

Ans : **Main 2003**

β-rays are stream of high energy electrons produced from the nucleus of a radioactive element after decay.

Therefore β-rays are not electromagnetic waves.

Thus (b) is correct option.

14. Which radiation in sunlight causes heating effect?

(a) ultra violet (b) infra-red

(c) visible light (d) all of these

Ans : **SQP 2001**

Wavelength of infra-red radiation extends from 8×10^{-7}m to 4×10^{-3} m. These radiations have longer wavelength and can penetrate deeply into the materials, causing heating effect.

Thus (b) is correct option.

15. Which of the following electromagnetic waves have minimum frequency ?

(a) radio-waves (b) ultrasonic-waves

(c) audible-waves (d) micro-waves

Ans : **Main 2015, 2010**

Wavelength of a wave is inversely proportional to its frequency. Therefore larger the wavelength, smaller is the frequency. Since the audible waves have maximum wavelength, therefore they have minimum frequency.

Thus (c) is correct option.

Thus (a) is correct option.

16. Which of the following groups belongs only to the electromagnetic spectrum?

(a) Alpha rays, beta rays, gamma rays

(b) Ultrasonic rays, radio waves, infrared rays

(c) Gamma rays, cathode rays, X-rays

(d) X-rays, radio waves, infrared rays

Ans : **Main 2022 Sem-I**

Electromagnetic spectrum consists of electromagnetic waves such as radio waves, infrared rays, visible light, ultraviolet rays, X-rays, and gamma rays. Alpha rays, beta rays, cathode rays, and ultrasonic waves are not electromagnetic waves. Therefore, only option (d) contains electromagnetic waves only.

Thus (d) is correct option.

17. Consider four electromagnetic radiations namely infrared radiations, ultraviolet radiations, microwaves and light. Which one of these has maximum frequency?

(a) Infrared radiations

(b) Ultraviolet radiations

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(c) wavelength is halved and frequency remains unchanged.

(d) wavelength is doubled and the frequency remains unchanged.

Ans : **Main 2014, 2010**

Frequency, $v = 3$ MHz

and dielectric constant of medium,

$$k = 4$$

Refractive index of medium,

$$\mu = \sqrt{\frac{\varepsilon}{\varepsilon_0}}$$

$$= \sqrt{\frac{k\,\varepsilon_0}{\varepsilon_0}} = \sqrt{k} = \sqrt{4} = 2$$

and wavelength of electromagnetic wave in medium,

$$\lambda = \frac{\lambda}{\mu} = \frac{\lambda}{2}$$

(where $\lambda =$ Wavelength of wave is vacuum)

Since, frequency of wave is independent of the medium, therefore it remains unchanged.

Thus (c) is correct option.

ASSERTION AND REASON

31. **Assertion :** X-ray travel with the speed of light.

Reason : X-rays are electromagnetic rays.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **Main 2004**

All electromagnetic waves have same speed in vacuum. X-ray is a high energy electromagnetic wave.

Thus (a) is correct option.

32. **Assertion :** Radio waves can be polarised.

Reason : Sound waves in air are longitudinal in nature.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **Main 2015**

Radio waves can be polarised because they are transverse in nature. Sound waves in air are longitudinal in nature.

Thus (c) is correct option.

33. **Assertion :** Microwaves are better carrier of signals than optical waves.

Reason : Microwaves move faster than optical waves.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **SQP 2013**

The optical waves used in optical fibre communication are better carrier of signals than microwaves. The speed of microwave and optical wave is the same in vacuum.

Thus (d) is correct option.

34. **Assertion :** Dipole oscillations produce electromagnetic waves.

Reason : Accelerated charge produces electromagnetic waves.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **Comp 2012**

Hertz produced em waves by oscillating charge between dipole electric field.

A charge moving with non-zero acceleration where both magnetic and electric field are varying emits em waves but this does not explain assertion.

Thus (b) is correct option.

35. **Assertion :** Environmental damage has increased the amount of ozone in the atmosphere.

Reason : Increase of ozone increases the amount of ultraviolet radiation of earth.

(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

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(b) Both Assertion and Reason are correct, but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

Ans : **Main 2007**

Ozone layer in the stratosphere helps in protecting life of organism form ultraviolet radiation on earth. Ozone layer is depleted due to of several factors like use of chlorofluro carbon (CFC) which is the cause of environmental damages.
Thus (a) is correct option.

ONE MARK QUESTIONS

36. How are microwaves produced ?

Ans : **SQP 2011**

By using a magnetron.

37. To which part of the electromagnetic spectrum does a wave of frequency 5×10^{19} Hz belong ?

Ans : **Comp 2019**

A wave of frequency 5×10^{19} Hz belong to γ-rays of electromagnetic spectrum.

38. Do electromagnetic waves carry energy and momentum ?

Ans : **SQP 2015**

Yes, Electromagnetic waves carry energy and momentum.

39. To which part of the electromagnetic spectrum does a wave of frequency 5×10^{19} Hz belong ?

Ans : **Main 2025, 2014**

X-rays or γ-rays.

40. How are radio waves produced ?

Ans : **SQP 2017**

They are produced by rapid acceleration and de-accelerations of electrons in aerials.

41. Name the physical quantity which remains same for microwaves of wavelength 1 mm and UV radiations of 1600 Å in vacuum.

Ans : **SQP 2010**

Velocity.

42. To which part of the electromagnetic spectrum does a wave of frequency 3×10^{13} Hz belong ?

Ans : **Comp 2016**

The frequency of 3×10^{13} Hz belong to the infrared waves.

43. Name the physical quantity which remains same for microwaves of wavelength 1 mm and UV radiations of 1600 Å in vacuum.

Ans : **SQP 2020**

Velocity ($c = 3 \times 10^8$ m/s)
This is because both are electromagnetic waves.

44. The speed of an electromagnetic wave in a material medium is given by $V = \frac{1}{\sqrt{\mu\varepsilon}}$, μ being the permeability of the medium and ε its permittivity. How does its frequency change ?

Ans : **Main 2021**

The frequency of electromagnetic waves does not change while travelling through a medium.

45. What physical quantity is the same for X-rays of wavelength 10^{-10} m, red light of wavelength 6800 Å and radio-waves of wavelength 500 m ?

Ans : **Main 2013**

X-rays, red light and radio waves are all electromagnetic waves. The speed of propagation in vacuum is the same for all these waves. This speeds is equal to $c = 3 \times 10^8$ m/s.

46. What is the frequency of electromagnetic waves produced by oscillating charge of frequency $v = 10^5$ Hz ?

Ans : **SQP 2021**

The frequency of electromagnetic waves produced by oscillating charge of frequency is radio wave (10^4 Hz to 10^8 Hz).

47. A plane electromagnetic wave travels in vacuum along z-direction. What can you say about the direction of electric and magnetic field vectors ?

Ans : **Comp 2020**

Electric field vector along X-axis and magnetic field vector along Y-axis.

48. Name the electromagnetic waves, which (i) maintain the Earth's warmth and (ii) are used in aircraft navigation.

Ans : **SQP 2012, 2009**

(i) Infrared rays
(ii) Microwaves

49. Write two uses of X-rays.

Ans : **Main 2018**

Uses of X-rays :
(i) In medical diagnosis as they pass through the muscles not through the bones.
(ii) In detecting faults, cracks, etc. in metal products.

NODIA

50. Write two uses of infrared rays.

Ans : **Comp 2018**

Uses of Infrared rays

(i) In knowing the molecular structure.

(ii) In remote control of TV, VCR, etc.

51. Write one use each of them :

1. Microwaves
2. x-rays

Ans : **Main 2010**

1. **Microwaves :** They are used in RADAR devices.
2. **γ-rays :** It is Used in radio therapy.

52. To which regions of the electromagnetic spectrum do the following wavelength belong:

(a) 250 nm (b) 1500 nm

Ans : **Main 2024**

(a) Wavelength 250 nm corresponds to the visible region of electromagnetic spectrum.

(b) Wavelength 1500 nm corresponds to the infrared region of electromagnetic spectrum.

53. Which electromagnetic radiation has wavelength greater than that of X-rays and smaller than that of visible light?

Ans : **Main 2012**

Wavelength of ultraviolet radiation (1×10^{-8} m to 4×10^{-7} m)lies in between X-ray and visible light. It is shorter than light wave (4×10^{-7} to 8×10^{-7} m) and longer than X-ray (1×10^{-11} to 3×10^{-8} m).

54. Arrange the following electromagnetic waves in the descending order of their wavelength.

1. Microwaves
2. Infrared rays
3. Ultraviolet radiation
4. x-rays

Ans : **Comp 2014**

The decreasing order of wavelength of electromagnetic waves are Microwaves > Infrared > Ultraviolet > x-rays.

55. In which part of electromagnetic spectrum, do the following radiations lie

(i) having wavelength of 20 nm.

(ii) having frequency of 10 MHz.

Ans : **Main 2009**

Electromagnetic waves lies in the region of

(i) X-rays [wavelength, $\lambda = 20$ nm]

(ii) radio-waves [frequency, $v = 10$ MHz]

56. Write an expression for the pressure exerted by an electromagnetic wave.

Ans : **Comp 2017, 2012**

When an electromagnetic wave falls on a surface, it exerts pressure on the surface. This pressure is called radiation pressure. The radiation pressure for an electromagnetic wave of intensity I is given by,

$$P_r = \frac{1}{c}$$

For visible light, $P_r = 7 \times 10^{-6}\,\text{Nm}^{-2}$

57. How does oscillating charge produce electromagnetic waves?

Ans : **Main 2013**

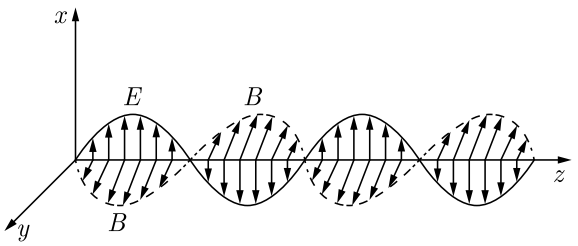
An oscillating charge produces an oscillating electric field in space, which produces an oscillating magnetic field. The oscillating electric and magnetic fields regenerate each other and this results in the production of electromagnetic waves in space.

58. Sketch a schematic diagram depicting oscillating electric and magnetic fields of an electromagnetic wave propagating along + z-direction.

Ans : **SQP 2009**

Electric

field is along x-axis and magnetic field is along y-axis.



59. Welders wear special goggles or face masks with glass windows to protect their eyes from electromagnetic radiation. Name the radiations and write the range of their frequency.

Ans : **Main 2015**

Welders wear special goggles or face masks with glass windows to protect their eyes from ultraviolet (UV) rays and infrared (IR) rays produced during welding. These radiations are harmful to the eyes and can cause serious damage if proper protection is not used.The range of UV rays is 4×10^{-7} m (400 nm) to 6×10^{-10} m (0.6 nm).

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TWO MARKS QUESTIONS

60. State any one source of ultraviolet radiations.

Ans : Main 2015

The Sun is our primary natural source of ultraviolet radiation.

61. Name an electromagnetic wave which is used in the RADAR system for aircraft navigation.

Ans : SQP 2017

Microwaves are used in the RADAR system for aircraft navigation.

62. Which electromagnetic radiation is used to study the crystal structure

Ans : SQP 2011

X-rays can be reflected and diffracted by the crystals. Hence, it is used to study the crystal structure.

63. What is the ratio of the speed of gamma rays to that of radio waves in vacuum?

Ans : Main 2018, 2014

The speed of gamma rays and radio waves in vacuum are same. So, the ratio of speed of gamma rays to that of radio waves will be 1 : 1.

64. Name the electromagnetic wave/radiation which is used to study crystal structure.

Ans : Main 2009

To study the structure of crystals, we use X-rays as the distance between 2 atoms in a crystal is very similar to wavelength of X-rays.

65. State any one use of infrared radiations.

Ans : Main 2020

Infrared radiations are used in thermal imaging cameras, which allow a fire fighter to see areas of heat through smoke, darkness or heat permeable barriers.

66. What is displacement current?

Ans : SQP 2025

Displacement current is a current which is produced due to the rate of change of electric flux with respect to time. It is given by

$$I_d = \varepsilon_0 \frac{d}{dt}(\phi_E)$$

67. Name the electromagnetic radiation

(i) used for viewing through haze and fog.

(ii) which has the wavelength of 0.1 nm.

Ans : SQP 2023

(i) Infrared rays are used for viewing objects through haze and fog.

(ii) X-rays have a wavelength of nearly 0.1 nm.

68. Microwaves, X-rays, UV-rays, infrared rays. Which of the above electromagnetic waves has

(i) the shortest wavelength?

(ii) the lowest frequency?

Ans : Main 2005

(i) The X-rays has the shortest wavelength.

$$[\lambda = 20\,\text{nm}]$$

(ii) Microwaves has the lowest frequency.

69. Write two main features of LASER rays.

Ans : SQP 2015

Two mean features of LASER rays are following

1. A laser beam is collimated, meaning it consists of waves travelling parallel to each other in single direction.
2. Laser light is coherent, which means all the light wave move in phase together in both time and space.

NODIA

70. Write any two properties of X-rays.

Ans : Main 2013

Two properties of X-rays are as follows :

1. The range of wavelength of X-ray is 1 mm to 10^{-3} nm.
2. They gives the luminous effect on photo graphic plates.

71. Identify the electromagnetic waves whose wave lengths vary as

(a) $10^{-12}\,\text{m} < \lambda < 10^{-8}\,\text{m}$

(b) $10^{-13}\,\text{m} < \lambda < 10^{-1}\,\text{m}$

Ans : SQP 2017

(a) ***X*-rays :** Use of study atomic structure.

(b) **Microwaves :** For cooking in microwaves ovens.

72. State any two properties of microwaves.

Ans : Main 2019

Two properties of microwaves are as follows :

(i) Microwaves have wavelength such that they induces vibration in liquid contained in the foods. Thus, they are used to cook food.

(ii) Microwaves can reflect and focused at any point after reflection from a particular substance (usually metal).

73. What is the importance of ozone layer in the atmosphere?

Ans : Comp 2017

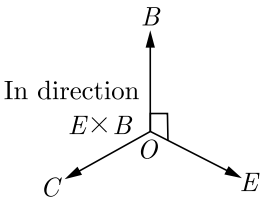
The solar radiation consists of ultraviolet and some other lower wavelength radiations which cause genetic damages to living cells. The ozone layer absorbs these radiations from the sun and

prevents them from reaching the earth's surface and causing damage to life. Moreover, it also keeps the earth's surface warm by trapping infrared radiation.

74. State how vector $\vec{E}$, $\vec{B}$ and $\vec{c}$ are oriented in an electromagnetic wave.

Ans : **Main 2023**

In a electromagnetic wave $\vec{E}$, and $\vec{B}$ are perpendicular to each other and (i.e propagation of electromagnetic wave) is perpendicular to both $\vec{E}$ and $\vec{B}$



75. Find the wavelength of electromagnetic waves of frequency 6×10^{12} Hz in free space. Give its two applications.

Ans : **SQP 2024**

Wavelength, $\lambda = \frac{c}{v} = \frac{3 \times 10^8}{6 \times 10^{12}}$

$= 5 \times 10^{-5}$ m

This wavelength corresponds to infrared waves.

Applications of Infrared Rays

(i) They are used in green houses to warm the plants.

(ii) They are used in taking photographs during fogs.

76. How are X-rays produced ? Give any two uses of these.

Ans : **SQP 2023**

X-rays are produced when high energetic electron beam is made incident on a metallic target of high melting point and high atomic weight.

Uses :

1. **In Engineering :** Using X-rays, cracks produced in buildings or bridges can be detected and the accidents can be avoided.
2. **In radiotherapy :** X-Rays can pass easily through the material of low density like skin, flesh, blood etc. On its basis, Many diseases can be detected cancer is also treated with X-rays.

77. Mention some sources of electromagnetic waves.

Ans : **SQP 2015, 2011**

An accelerating charge produces electromagnetic waves. An electric charge oscillating harmonically with frequency ν, generates electromagnetic waves of the same frequency ν.

An electric dipole is a basic source of electromagnetic waves.

An LC-circuit containing inductance L and capacitance C produces electromagnetic waves of frequency,

$$\nu = \frac{1}{2\pi\sqrt{LC}}$$

78. What is displacement current? Why was this concept introduced?

Ans : **Comp 2021**

It is that current which comes into existence (in addition to conduction current) whenever the electric field and hence the electric flux changes with time. It is equal to ε_0 times the rate of change of electric flux through a given surface.

$$I_d = \varepsilon_0 \frac{d\phi_E}{dt} = \varepsilon_0 A \frac{dE}{dt}$$

Maxwell introduced the concept of displacement current for the following reasons:

1. To make the Ampere's circuital law logically consistent.
2. To satisfy the property of continuity of electric current along any closed path.

79. Name the part of the electromagnetic spectrum which is

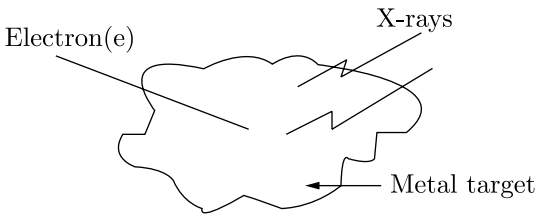
(i) suitable for radar systems used in aircraft navigation.

(ii) produced by bombarding a metal target with high speed electrons.

Ans : **Main 2014**

(i) Microwaves are suitable for radar systems used in aircraft navigation.

(ii) When a metal target is bombarded with high speed electrons, X-rays are produced.



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80. State the important properties of displacement current.

Ans : **Main 2020**

These are as follows :

1. Displacement current exists whenever there is a change of electric flux. Unlike conduction current, it does not exist under steady conditions.
2. It is not a current. It only adds to current density in Ampere's circuital law. As it produces magnetic field, so it is called a current.
3. The magnitude of displacement current is equal to the rate of displacement of charge from one capacitor plate to the other.
4. Together with the conduction current, displacement current satisfies the property of continuity.

81. State Maxwell's equations.

Ans : **Comp 2025**

The whole study of electricity and magnetism can be described mathematically with the help of four fundamental equations, called Maxwell's equations. These are stated as follows:

1. Gauss Law of Electrostatics :

$$\oint \vec{E} \cdot \vec{d}S = \frac{q}{\varepsilon_0}$$

2. Gauss Law of Magnetism :

$$\oint \vec{B} \cdot \vec{d}S = 0$$

3. Faraday Law of Electromagnetic Induction :

$$\oint \vec{E} \cdot \vec{d}l = -\frac{d\phi_B}{dt}$$

$$= -\frac{d}{dt}\left[\oint \vec{B} \cdot \vec{d}S\right]$$

4. Modified Ampere's Circuital Law :

$$\oint \vec{B} \cdot \vec{d}l = \mu_0\left[I_c + \varepsilon_0 \frac{d\phi_E}{dt}\right]$$

82. Arrange the following electromagnetic waves in increasing order of their frequencies (i.e. begin with the lowest frequency):

Visible light, γ-rays, X-rays, microwaves, radio waves, infrared radiations and ultraviolet radiations.

Ans : **Main 2007**

Electromagnetic waves in increasing order of their frequencies are as follows.

$(3 \times 10^3$ to 3×10^8 Hz)

Radio waves < Microwaves < Infrared

$(4 \times 10^{14}$ Hz $\rightarrow 8 \times 10^{14}$ Hz)

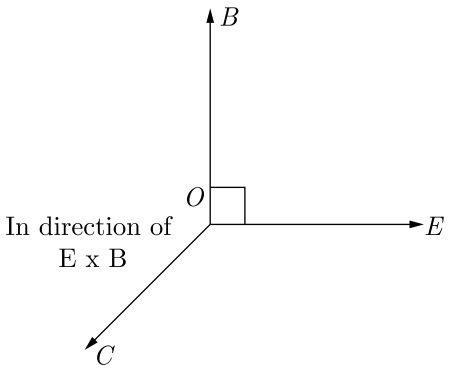
radiations < Visible light < Ultraviolet radiations < X-rays < Gamma rays

$(5 \times 10^{18} - 5 \times 10^{22}$ Hz)

83. In an electromagnetic wave, how are electric vector $(\vec{E})$, magnetic vector $(\vec{B})$ and velocity of propagation of the wave $(\vec{c})$ oriented?

Ans : **Main 2013, 2008**

In an electromagnetic waves, $\vec{E}$ and $\vec{B}$ are perpendicular to each other and c (i.e., propagation of electromagnetic wave) is perpendicular to both $\vec{E}$ and $\vec{B}$.



84. State any one property which is common to all electromagnetic waves.

Ans : **Main 2017**

One property which is common to all electromagnetic waves is as follows :

The energy associated with the EM waves is equally divided between electric and magnetic field.

Energy density of electric field,

$$u_e = \frac{1}{2}\varepsilon_0 E^2$$

Energy density of magnetic field,

$$u_B = \frac{1}{2}\frac{B^2}{\mu_0}$$

So, the total energy per unit volume is given as,

$$U = U_e + U_B$$

$$= \frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2}\frac{B^2}{\mu_0}$$

Also, the average energy density is,

$$u_{av} = \frac{1}{2}\varepsilon_0 E_0^2 = \frac{B_0^2}{2\mu_0}$$

THREE MARKS QUESTIONS

85. Which one of the following electromagnetic radiations has least frequency, UV radiations, X -rays, Microwaves ?

Ans : SQP 2015

Microwave.

86. Which one of the following electromagnetic radiations Write two important uses of infrared waves.

Ans : SQP 2011

(a) Associated with the green house effect.

(b) In remote switches off household electrical appliances.

87. Why are infrared waves often called as heat waves? Give their one application.

Ans : Main 2025

Infrared rays are called heat waves because they vary with temperature.

They are used in physical therapy, weather forecasting.

88. Name the electromagnetic waves which are used for the treatment of certain forms of cancer. Write their frequency range.

Ans : SQP 2014, 2011

γ-rays are used for the treatment of certain forms of cancer. Its frequency range is 3×10^{19} Hz to 5×10^{22} Hz.

89. Name the electromagnetic waves which are suitable for RADAR systems used in aircraft navigation. Write the range of frequency of these waves.

Ans : Main 2017

The electromagnetic waves suitable for RADAR system is microwaves. The range of frequency is 3×10^{11} to 1×10^{8} Hz.

90. If the earth not have atmosphere, would its average surface temperature be higher or lower than what it is now? Explain.

Ans : Main 2004

The temperature of the earth would be lower because the green house effect of the atmosphere would be absent.

91. An electromagnetic wave exerts pressure on the surface on which it is incident. Justify.

Ans : Main 2003

An electromagnetic waves has momentum,

i.e., $$p = \frac{\text{Energy}\,(E)}{\text{Velocity of light}\,(c)}$$

When it is incident upon a surface it exerts pressure on it.

92. Name the waves which are produced during radioactive decay of a nucleus. Write their frequency range.

Ans : Main 2010

γ-rays are produced during radioactive decay of a nucleus. Its frequency range is from 3×10^{18} to 5×10^{22} Hz.

93. Welders wear special glass goggles while working. Why ? Explain.

Ans : Main 2010

Welders wear special goggles of face mask with glass windows to protect their eyes from ultraviolet rays. The range of UV rays is 4×10^{-7} m to 6×10^{-10} m.

94. Write the expression for the energy density of an electromagnetic wave propagating in free space.

Ans : Main 2016

The electromagnetic wave consists of oscillating electric and magnetic fields, So net energy density of electromagnetic wave is

$$U = U_E + U_B$$

$$U = \frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2}\frac{B^2}{\mu_0}$$

95. Thin ozone layer on top of stratosphere is crucial for human survival. Why ?

Ans : Main 2010

The thin ozone layer on top of stratosphere absorbs most of the harmful ultraviolet rays coming from the sun towards the earth. They include UVA, UVB and UVC radiations, which can destroy the life system on the earth.

Hence, this layer is crucial for human survival.

96. State clearly how a microwave oven works to heat up a food item containing water molecules.

Ans : Main 2011

In microwave oven, the frequency of the microwaves is selected to match the resonant frequency of water molecules so that energy from the waves get transferred efficiently to the kinetic energy of the molecules. This kinetic energy raises the temperature of any food containing water.

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Ans : SQP 2012

Electromagnetic wave produced by oscillating charged particle.

Mathematical expression for electromagnetic wave travel along z-axis.

$$E_x = E_0 \sin(kz - \omega t) \quad \text{[For electric field]}$$

$$B_y = B_0 \sin(kz - \omega t) \quad \text{[For magnetic field]}$$

Properties :

1. Have oscillating electric and magnetic fields along mutually perpendicular direction.
2. Transverse nature.

114. State two properties of electromagnetic waves. How can we show that electromagnetic waves carry momentum?

Ans : Main 2017

Properties of electromagnetic waves

1. Transverse nature.
2. Does not get deflected by electric fields or magnetic fields.
3. Same speed in vacuum for all waves.
4. No material medium required for propagation.
5. They get refracted, diffracted and polarised.

Electric charges present on a plane, kept normal to the direction of propagation of an electromagnetic wave can be set and sustained in motion by the electric and magnetic field of the electromagnetic wave. The charges thus acquire energy and momentum from the waves.

115. A capacitor of capacitance C is being charged by connecting it across a DC source along with an ammeter. Will the ammeter show a momentary deflection during the process of charging? If so, how would you explain this momentary deflection and the resulting continuity of current in the circuit? Write the expression for the current inside the capacitor.

Ans : SQP 2024, 2010

The ammeter will show the momentary deflection.

This momentary deflection occurs due to the fact that the conduction current flows through connection wires during the charging of capacitor. This lead to gathering of charge at two plated and hence varying electric field of increasing nature is produced between the plated which in turn produce displacement current in space between two plates. This maintains the continuity with the conduction current.

$$I_c = I_d$$

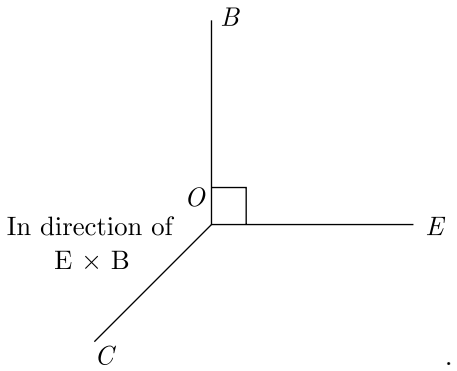
The current inside the capacitor,

Displacement current I_c and $I_d = \varepsilon_0 \frac{d\phi_E}{dt}$.

116. State how electric vector $\vec{E}$, magnetic vector $\vec{B}$ and velocity vector $\vec{c}$ are oriented in an electromagnetic wave?

Ans : SQP 2001

In an electromagnetic waves, $\vec{E}$ and $\vec{B}$ are perpendicular to each other and c (i.e., propagation of electromagnetic wave) is perpendicular to both $\vec{E}$ and $\vec{B}$.



117. Briefly explain how Maxwell was led to predict the existence of electromagnetic waves.

Ans : SQP 2017

According to Faraday law of electromagnetic induction, **A time-varying magnetic field is a source of changing electric field.**

On the basis of his theoretical studies, Maxwell in 1865, argued that, **A time-varying electric field is a source of changing magnetic field.** This means that the change in either field (electric/magnetic) produces the other field. Maxwell further showed that these variations in electric and magnetic fields occur in mutually perpendicular directions and have wave like properties. He was thus led to the idea that a wave of electric and magnetic fields both varying with space and time should exist, one providing the source of the other. Such a wave is called an electromagnetic wave and it indeed exists.

118. Write Maxwell's generalization of Ampere's Circuital Law. Show that in the process of charging a capacitor, the current produced within the plates of the capacitor is

$$i = \varepsilon_0 \frac{d\phi_E}{dt}$$

Where ϕ_E is the electric flux produced during charging of the capacitor plates.

Ans : Main 2006

Ampere's circuital law is given by

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 I_C$$

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to a surface in time t, then total linear momentum delivered to the surface is,

$$p = \frac{U}{c} \text{ [For complete absorption of energy } U\text{]}$$

If the wave is totally reflected, the momentum delivered will be $\frac{2U}{c}$, because the momentum of the wave will change from p to $-p$.

107. Out of electric field vector $\vec{E}$ and magnetic field vector $\vec{B}$ in an electromagnetic wave, which is more effective and why?

Ans : **SQP 2019, 2016**

Both the electric $\vec{E}$ and magnetic $\vec{B}$ vector are essential in the transmission of EM wave but in the interaction with matter the electric vector $\vec{E}$ is more important.

When a photon impacts a rod or cone on your retina it is the E-vector that donates its energy to the light sensitive molecule, resulting in excitation and hence a signal to your brain. Also in polarization, $\vec{E}$ is important.

108. How do you convince yourself that electromagnetic waves carry energy and momentum?

Ans : **SQP 2015**

According to the quantum theory, electromagnetic radiation is made up of massless particles called photons. Momentum of the photon is expressed as

$$p = \frac{E}{c}$$

where, p = momentum

E = energy

and c = speed of light

Thus, we are convinced that electromagnetic wave carry energy and momentum.

109. Arrange the following electromagnetic waves in the order of their increasing wavelength

(a) Gamma (γ) rays

(b) Microwaves

(c) X-rays

(d) Radio waves

Ans : **Main 2016**

Gamma (γ) rays, X-rays, Microwaves, Radio-waves.

Infrared rays are produced by hot bodies/ vibration of atoms and molecules.

Infrared rays (i) Maintain Earth's warmth through greenhouse effect, (ii) Produce heat.

110. How are infrared waves produced? Why are these referred to as heat waves? Write their one important use.

Ans : **Main 2019, 2023**

Infrared waves are produced by hot bodies and molecules. Infrared waves are sometimes referred to as heat waves. This is because water molecules present in most materials readily absorb infrared waves. After absorption, their thermal motion increases, that is they heat up and heat their surroundings.

Infrared lamps are used in physical therapy and in remote control of devices.

111. Explain briefly how electromagnetic waves are produced by an oscillating charge. How is the frequency of electromagnetic waves produced related to that of the oscillating charge?

Ans : **Main 2008**

An oscillating or accelerated charge is supposed to be sources of an electromagnetic wave. An oscillating charge produces an oscillating electric field in space which further producers an oscillating magnetic field which in turn is a source of electric field. These oscillating electric and magnetic field, hence, keep on regenerating each other and an electromagnetic wave is produced. The frequency of electromagnetic wave = Frequency of oscillating charge.

112. How do you show that electromagnetic waves carry energy and momentum ?

Ans : **Main 2012, 2007**

When a charge oscillates with some frequency, it produces an oscillating electric field and magnetic field in space. So, an electromagnetic wave is produced.

The frequency of the electromagnetic wave is equal to the frequency of oscillation of the charge.

Hence, energy associated with the electromagnetic wave comes at the expense of the energy of the source.

If the electromagnetic wave of energy U strikes on a surface and gets completely absorbed, total momentum delivery to the surface is $p = \frac{U}{E}$.

Hence electromagnetic wave also carry momentum.

113. How are electromagnetic waves produced? What is the source of energy of these waves? Write mathematical expressions for electric and magnetic fields of an electromagnetic wave propagating along the z-axis. Write any two important properties of electromagnetic waves.

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97. Why are microwaves found useful for the RADAR systems in aircraft navigation ?

Ans : **Main 2017**

Microwaves are short wavelength radio waves, with frequency of order of few GHz. Due to short wavelength, they have high penetrating power with respect to atmosphere and less diffraction in the atmospheric layers. So, these waves are suitable for the radar systems used in aircraft navigation.

98. Which segment of electromagnetic waves has highest frequency ? How are these waves produced ? Give one use of these waves.

Ans : **Comp 2016**

Gamma rays have the highest frequency. These are produced during nuclear reactions and also emitted by radioactive nuclei. They are used in medicine to destroy cancer cells.

99. Identify the part of the electromagnetic spectrum which is

(a) suitable for radar system used in aircraft navigation.

(b) produced by bombarding a metal target by high speed electrons.

Ans : **Main 2018**

(a) Microwaves

(b) X-rays

100. Describe briefly how electromagnetic waves are produced by oscillating charges.

Ans : **Comp 2024**

Electromagnetic waves are produced by accelerated charges. An oscillating charge produces an oscillating magnetic field which in its own turn is a source of oscillating electric field. The oscillating electric and magnetic fields thus regenerate each other i.e., they produce electromagnetic waves through space.

101. Give one use of each of the following :

(i) Microwaves

(ii) Ultraviolet rays

(iii) Infrared rays

(iv) Gamma rays

Ans : **SQP 2013**

(i) **Microwaves :** In cooking and communication.

(ii) **Ultraviolet rays :** Photocells and in sterilizing the surgical equipment.

(iii) **Infrared rays :** Photography and physical therapy.

(iv) **Gamma rays :** In cancer treatment and study of structure of atomic nucleus.

102. Show, by giving a simple example, how electromagnetic waves carry energy and momentum.

Ans : **SQP 2014**

Consider a plane perpendicular to the direction of propagation of the wave. An electric charge, on the plane will be set in motion by the electric and magnetic fields of electromagnetic wave, incident on this plane. This illustrates that electromagnetic waves carry energy and momentum.

103. How are microwaves produced ? Why is it necessary in microwaves ovens to select the frequency of microwaves to match the resonant frequency of water molecules ?

Ans : **Main 2009**

Microwaves are produced by special vacuum tube like the klystron, magnetron and Gunn diode.

The frequency of microwaves is selected to match the resonant frequency of water molecules, so that energy is transformed efficiently to the kinetic energy of the molecules.

104. Why is the amount of the momentum transferred by the electromagnetic waves incident on the surface so small ?

Ans : **SQP 2014**

Momentum transferred

$$= \text{Energy} \times \text{Speed of light}$$

$$= hvc = 10^{-22}$$

Thus, the amount of the momentum transferred by the electromagnetic waves incident on the surface is very small.

105. Name any two electromagnetic waves. State any one similarity and one difference between them

Ans : . **Main 2007, 2003**

Example of two electromagnetic waves are microwaves and radio-waves.

Similarity Both the waves travel with the same speed in vacuum as the speed of light (3×10^8 m/s).

Difference Radio-waves are having frequency range 3×10^9 to 3×10^4 Hz while microwaves are having frequency range 3×10^{11} to 1×10^9 Hz.

106. Write an expression for the momentum carried by an E.M. wave.

Ans : **SQP 2012**

An electromagnetic wave transports linear momentum as it travels through space. If an electromagnetic wave transfers a total energy U

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For a circuit containing capacitor, during its charging or discharging the current within the plates of the capacitor varies producing displacement current I_d. Hence, Ampere's circuital law is generalised by Maxwell, given as

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 \ I_C + \mu_0 I_d$$

The electric flux (ϕ_E) between the place of capacitor changes with time, producing current within the plates which is proportional to $\left(\frac{d\phi_E}{dt}\right)$ .Thus, we get,

$$I_C = \varepsilon_0 \frac{d\phi_E}{dt} \varepsilon$$

119. State the important consequences of displacement current.

Ans : **SQP 2020**

The concept of displacement current has made the laws of electricity and magnetism symmetrical. According to Faraday law of electromagnetic induction, the magnitude of induced emf is equal to the rate of change magnetic flux. But the emf between two points is the work done in taking a unit charge from one point to another against the electrostatic forces. This implies the existence of an electric field in the region. So Faraday's law simply states that a time varying magnetic field gives rise to an electric field.

By symmetry, a time varying electric field should give rise to a magnetic field. This is an important consequence of displacement current which is a source of magnetic field.

Another very important consequence of the symmetry of electricity and magnetism is the existence of electromagnetic waves.

120. Write the expression for the generalised form of Ampere's circuital law. Discuss its significance and describe briefly how the concept of displacement current is explained through charging/discharging of a capacitor in an electric circuit.

Ans : **Comp 2017, 2010**

The generalisation in Ampere's circuital law was modified by Maxwell, as

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 (I_C + I_d) = \mu_0 I_C + \mu_0 I_d$$

$$= \mu_0 I_C + \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}$$

where, $I_d = \varepsilon_0 \frac{d\phi_E}{dt}$ is displacement current.

Significance : This expression signifies that the source of magnetic field is not just due to the conduction current in the metallic conductors, but also due to the time rate of change of electric flux called displacement current.

During charging and discharging of a capacitor, electric field between the plates will change. Hence, there will be a change in electric flux, called displacement current, between the plates.

121. Name the parts of the electromagnetic spectrum which is

(i) suitable for RADAR systems in aircraft navigations.

(ii) used to treat muscular strain.

(iii) used as a diagnostic tool in medicine.

Write in brief, how these waves can be produced.

Ans : **SQP 2006**

The electromagnetic waves suitable for RADAR system is microwaves. The range of frequency is 3×10^{11} to 1×10^{8} Hz.

(i) These rays are produced by special vacuum tubes, namely klystrons, magnetron's and Gunn diodes.

(ii) Infrared waves are used to treat muscular strain. These rays are produced by hot bodies and molecules.

(iii) X-rays are used a diagnostic tool in medicine. These rays are produced when high energy electrons are stopped suddenly on a metal of high atomic number.

122. Write the expression for electrical energy density and magnetic energy density associated with electromagnetic wave and show that their ratio is 1.

Ans : **SQP 2011**

Electrical energy density,

$$u_E = \frac{1}{2} \varepsilon_0 E^2 \qquad ...(1)$$

Magnetic energy density,

$$u_B = \frac{B^2}{2\mu_0} \qquad ...(2)$$

Dividing Eq. (1) by (2),

$$\frac{u_E}{u_B} = (\varepsilon_0 \mu_0) \left(\frac{E}{B}\right)^2 \qquad ...(3)$$

Since, $E = cB$

$$c^2 = \frac{1}{\mu_0 \varepsilon_0}$$

Hence, $\frac{u_E}{u_B} = \frac{1}{c^2} \left(\frac{E}{B}\right)^2$

$$\frac{u_F}{u_B} = \frac{1}{c^2} \times c^2 \qquad \left[\text{Since}, c = \frac{E}{B}\right]$$

$$= 1$$

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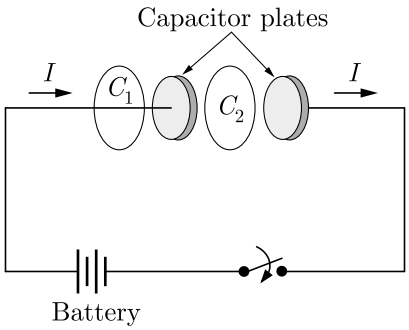
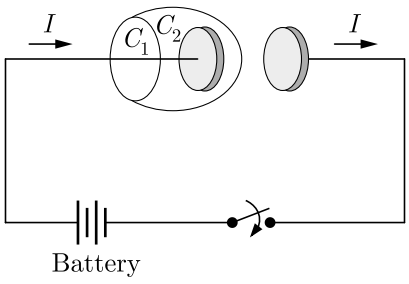
the capacitor gap as no charge is transported across this gap.

$$I_c = \frac{dq}{dt}$$



(a)



(b)

A parallel plate capacitor being charged by a battery

The displacement current I_d is zero outside the capacitor plates and in the gap, it has the value,

$$\varepsilon_0 \frac{d\phi_E}{dt} = \varepsilon_0 \frac{d}{dt}(EA)$$

$$= \varepsilon_0 \frac{d}{dt}\left(\frac{q}{\varepsilon_0}\right) = \frac{dq}{dt}$$

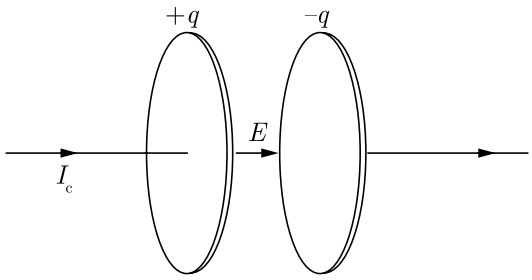
which is exactly the value of the conduction current in the lead wires. Thus the displacement current satisfies the basic condition that the current is continuous.

The sum $I_c + \varepsilon_0 \frac{d\phi_E}{dt}$ has the same value along the entire path (both inside and outside the capacitor plates), although individually the two currents are discontinuous.

130. A capacitor made of two parallel plates each of plate area A and separation d, is being charged by an external AC source. Show that the displacement current inside the capacitor is the same as the current charging the capacitor.

Ans : **SQP 2018, 2013**

In figure conduction current is flowing in the wires, causes charge on the plates



So, $I_C = \frac{dq}{dt}$ ...(1)

According to Maxwell, displacement current between plates,

$$I_d = \varepsilon_0 \frac{d\phi_E}{dt}$$

where, ϕ_E = Electric flux ...(2)

Using Gauss's theorem, if one of the plate is inside the tiffin type Gaussian surface, then

$$\phi_E = \frac{q}{\varepsilon_0}$$

So, $$I_d = \varepsilon_0 \frac{d}{dt}\left(\frac{q}{\varepsilon_0}\right)$$

$$I_d = \frac{dq}{dt} \quad ...(3)$$

From equation (1) and (3), we get

Both conduction current and displacement current are equal.

131. When an AC source is connected across a capacitor, current starts flowing through the circuit. Show how Ampere's circuital law is generalized to explain the flow of current through the capacitor. Hence obtain the expression for the displacement current inside the capacitor.

Ans : **Main 2007, 2005**

Maxwell restated Ampere's circuital law as follows

$$\oint_C \vec{B} \cdot \vec{dl} = \mu_0(I + I_d) \quad ....(1)$$

where I_d is called the displacement current. This current arises due to the rate of change of electric flux (ϕ_E), between the plates of the capacitor and is given by

$$I_d = \varepsilon_0 \frac{d\phi_E}{dt} \quad ....(2)$$

Thus, the modified form of Ampere's circuital law, also called Ampere-Maxwell's circuital law, becomes

$$\oint_C \vec{B} \cdot \vec{dl} = \mu_0\left(I + \varepsilon_0 \frac{d\phi_E}{dt}\right)$$

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Name	Wavelength (in m)	Frequency (in Hz)	Source
γ-rays	6×10^{-14} to 1×10^{-10}	5×10^{20} to 3×10^{19}	Radioactive decay of the nucleus
X-rays	1×10^{-10} to 3×10^{-8}	3×10^{19} to 1×10^{16}	X-ray tubes or inner shell electrons
Ultraviolet rays	3×10^{-8} to 4×10^{-7}	10^{16} to 8×10^{14}	Excitation of atom, spark and arc lamp
Infrared rays	8×10^{-7} to 3×10^{-5}	4×10^{14} to 1×10^{13}	Excitation of atoms and molecules

127. Define intensity of an electromagnetic wave. Obtain an expression for it.

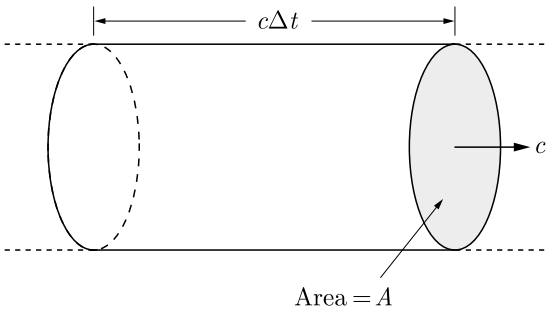
Ans : **Comp 2018**

The energy crossing per unit area per unit time in a direction perpendicular to the direction of propagation is called intensity of the wave.

Suppose a plane electromagnetic wave propagates along X-axis with speed c. As shown in figure, consider a cylindrical volume with area of cross-section A and length $c\Delta t$ along the X-axis. The energy contained in this cylinder crosses the area A in time Δt as the wave propagates with speed c. The energy contained is,

$$U = \text{Average energy density} \times \text{volume}$$
$$= u \times c\Delta t \times A$$

Intensity of the wave,



$$I = \frac{\text{Energy}}{\text{Area} \times \text{Time}} = \frac{U}{A\,\Delta t} = uc$$
$$= \frac{1}{2}\varepsilon_0 E_0^2 c = \varepsilon_0 E_{\text{rms}}^2 c$$

Also, $$I = \frac{1}{2\mu_0} B_0^2 c = \frac{1}{\mu_0} B_{\text{rms}}^2 c$$

Thus, the intensity of an electromagnetic wave is proportional to the square of the electric/ magnetic field.

128. Why does a galvanometer when connected in series with a capacitor show a momentary deflection, when it is being charged or discharged ? How does this observation lead to modifying the Ampere's circuital law ? Hence write the generalised expression of Ampere's law.

Ans : **Main 2015**

During charging or discharging of the capacitor, displacement current between the plates is produced. Hence, circuit becomes complete and galvanometer shows momentary deflection.

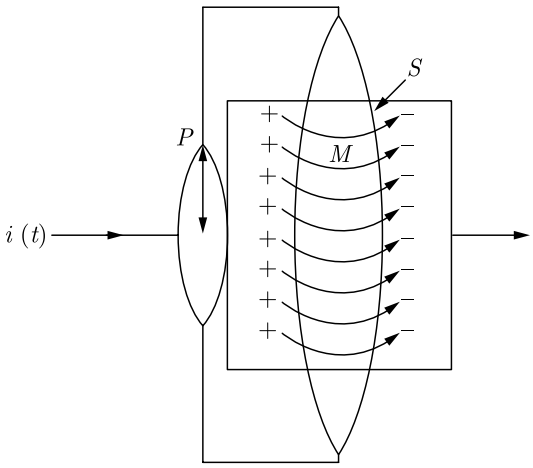
According to Ampere's circuital law

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 I$$

At surface P, $$\oint \vec{B} \cdot \vec{dl} = \mu_0 I_C$$

At surface S, $$\oint \vec{B} \cdot \vec{dl} = 0$$

Hence, $$\oint_P \vec{B} \cdot \vec{dl} \neq \oint_S \vec{B} \cdot \vec{dl}$$



This contradicts Ampere's circuital law. This law must be missing something. Hence the law needs modification. Modified form of Ampere's circuital law

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 \left[i_C + \varepsilon_0 \frac{d}{dt} \phi_E \right]$$

129. Conduction and displacement currents are individually discontinuous, but their sum is continuous.

Ans : **Main 2021**

In figure (as given below), a current I_c enters one plate and leaves the other plate of the capacitor. The conduction current is not continuous across

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141. A parallel plate capacitor is charged to $60\,\mu C$. Due to a radioactive source, the plate loses charge at the rate of 1.8×10^{-8} C-s^{-1}. What is the magnitude of displacement current?

Ans : SQP 2020

Charge on capacitor,

$$q = 60\,\mu C = 60 \times 10^{-6}\,C$$

and rate of losses of charge,

$$\frac{dq}{dt} = 1.8 \times 10^{-8}\,C\text{-}s^{-1}$$

electric field between the parallel plate capacitor,

$$E = \frac{q}{\varepsilon_0 A}$$

Therefore electric flux through the plate,

$$\phi_E = EA = \frac{q}{\varepsilon_0 A} \times A = \frac{q}{\varepsilon_0}$$

We also know that magnitude of displacement current,

$$I_d = \varepsilon_0 \frac{d\phi_E}{dt} = \varepsilon_0 \frac{d}{dt}\left(\frac{q}{\varepsilon_0}\right)$$

$$= \varepsilon_0 \times \frac{1}{\varepsilon_0}\frac{dq}{dt} = \frac{dq}{dt}$$

$$= 1.8 \times 10^{-8}\,C\text{-}s^{-1}$$

142. A parallel plate capacitor consists of two circular plates each of radius 2 cm separated by distance of 0.1 mm. If rate of change of potential difference is 5×10^{13} V-s^{-1}, Find out the value of displacement current ?

Ans : SQP 2019

Radius of each plates,

$$r = 2\,cm = 0.02\,m$$

Distance between the plates,

$$d = 0.1\,mm = 0.1 \times 10^{-3}\,m$$

and rate of change of potential difference,

$$\frac{dV}{dt} = 5 \times 10^{13}\,V\text{-}s^{-1}$$

area of circular plate,

$$A = \pi r^2 = \pi (0.02)^2 = 1.26 \times 10^{-3}\,m^2$$

Therefore displacement current,

$$I_d = \varepsilon_0 \frac{d\phi_E}{dt} = \varepsilon_0 \frac{d}{dt}(EA)$$

$$= \varepsilon_0 \frac{d}{dt}\left(\frac{V}{d} \times A\right) = \frac{\varepsilon_0 A}{d}\,\frac{dV}{dt}$$

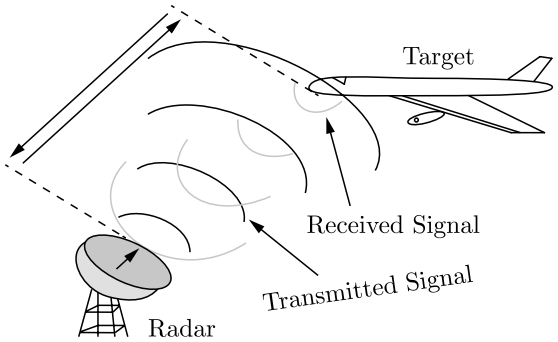
$$= \frac{(8.85 \times 10^{-12})(1.26 \times 10^{-3})}{0.1 \times 10^{-3}} \times (5 \times 10^{13})$$

$$= 5.6 \times 10^{3}\,A$$

(where, ε_0 = Absolute electric permittivity of free space equal to 8.85×10^{-12} C^2-N^{-1}-m^{-2})

CASE BASED QUESTIONS

143. Microwave is a form of electromagnetic radiation with wavelengths ranging from about one meter to one millimetre corresponding to frequencies between 300 MHz and 300 GHz respectively. Microwave are used in aircraft navigation. A radar guns out short bursts of microwave and it reflect back from oncoming aircraft and are detected by receiver in gun. The frequency of reflected wave used to compute speed of aircraft.



(a) How are microwave produced?
(b) Why microwave use for aircraft navigation?
(c) Which is use of microwave?
(d) Where do microwave fall in electromagnetic spectrum?

Ans :
(a) Klystron and magnetron valve.
(b) Due to low wavelength
(c) Studying details of atoms and molecule.
(d) Between infrared and radio wave.

144. The sunlight visible spectrum, discovered by Newton, extends in wavelength roughly from 4×10^{-7} m in the violet region to 8×10^{-7} m in the red region. After Newton, it was found that sun's spectrum is not limited from violet to red region, but is considerably spread below the violet region and also above the red region. These parts of the spectrum are not visible by our eye; so they are called 'invisible,spectra' of sun. The part of smaller wavelengths below violet is called the ultraviolet spectrum and that of longer wavelengths above red is called the infrared spectrum.

(i) Who was discovered the visible spectrum?
(ii) What is the range of Wavelength range of visible spectrum ?
(iii) In the electromagnetic spectrum, which radiation has maximum wavelength?

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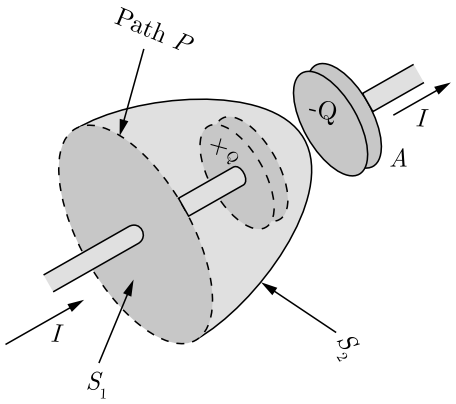


The term I equals zero if the surface S_2 is chosen and the term I_d equals zero, if S_1 is chosen. The term $\varepsilon_0 \frac{d\phi_E}{dt}$ has the dimension of current. The meaning of this expression can be understood by referring to figure.

The electric flux through S_2 is $\phi_E = \int \vec{E} \cdot \vec{d}A = EA$, where A is the area of the plates and E is the uniform electric field strength between the plates. If Q is the charge on the plates at any instant, then one finds that $E = \frac{Q}{\varepsilon_0 A}$.

Therefore, the electric flux through S_2 is simple

$$\phi_E = EA = \frac{Q}{\varepsilon_0}$$

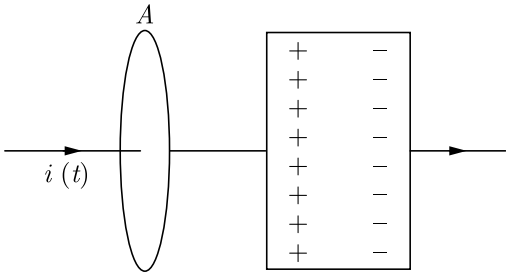
Hence, the displacement current I_d through S_2 is

$$I_d = \varepsilon_0 \frac{d\phi_E}{dt} = \frac{dQ}{dt} \qquad ...(3)$$

That is, displacement current is precisely equal to the conduction current I passing through S_1. The central point of this formalism is the fact that magnetic fields are produced both by conduction currents and by changing electric fields.

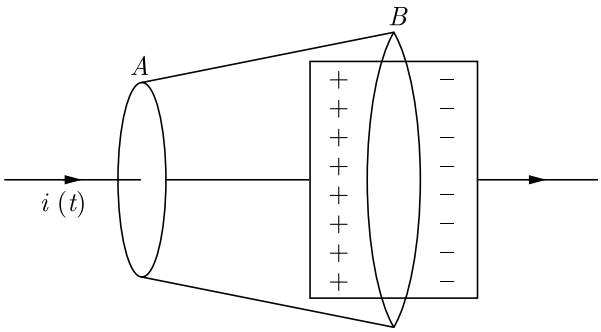
132. Considering the case of a parallel plate capacitor being charged, show how one is required to generalise Ampere's circuital law to include the term due to displacement current.

Ans : **SQP 2012**



During charging capacitor C, a time varying current $I(t)$ flows through the conducting wire, so on applying Ampere's circuital law (for loop A)

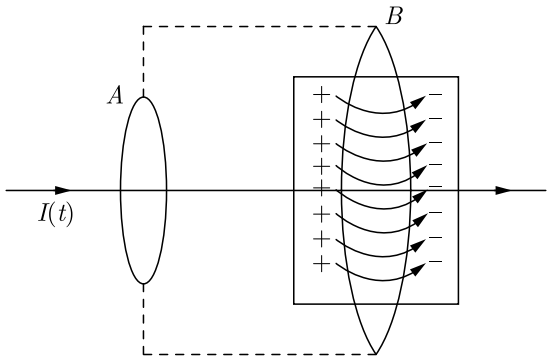
$$\oint \vec{B} \cdot \vec{dl} = \mu_0 I(t) \qquad ...(1)$$



Now, we consider a pot like surface enclosing the positively charged plate and nowhere touches the conducting wire,

$$\oint \vec{B} \cdot \vec{dl} = 0 \qquad ...(2)$$

From equation (1) and (2), we have a contradiction



If surface A and B forms a tiffin box and electric field $\vec{E}$ is passing through the surface (B); constitute an electric flux

$$\phi = E|A| = \frac{\sigma}{\varepsilon_0}|A|$$

$$= \frac{Q}{A\varepsilon_0} A = \frac{Q}{\varepsilon_0} \qquad ...(3)$$

If the charge on the plate in the tiffin box is changing with time, there must be a current between the plates.

From equation (3), we get

$$I = \frac{dQ}{dt} = \frac{d}{dt}(\varepsilon_0 \phi)$$

$$= \varepsilon_0 \frac{d\phi}{dt}$$

This is the missing term in Ampere's circuital law.

The inconsistency may disappear if displacement current is included between the plates.

So, generalised Ampere's circuital law can be given as

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 I(t) + \mu_0 I_d$$

$$= \mu_0 I(t) + \mu_0 \varepsilon_0 \frac{d\phi}{dt}$$

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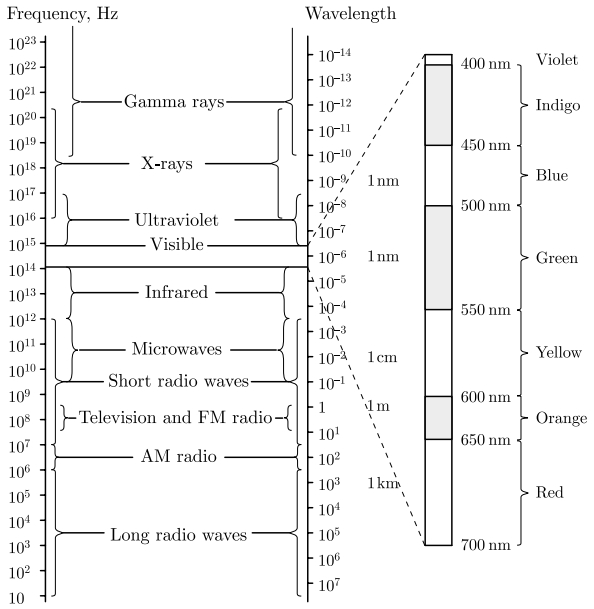
FOUR MARKS QUESTIONS

133. What is electromagnetic spectrum? Draw a sketch of electromagnetic spectrum indicating the frequency and wavelength ranges of its different parts.

Ans : SQP 2015

The orderly distribution of the electromagnetic waves in accordance with their wavelength or frequency into distinct groups having widely differing properties is called electromagnetic spectrum. As shown in figure, the main parts of the E.M. spectrum are γ-rays, X-rays, ultraviolet rays, visible light, infrared rays, microwaves and radio waves in the order of increasing wavelength from 10^{-2} Å or 10^{-12} m to 10^{6} m.



134. Obtain expression for the energy density of an electromagnetic wave. In an electromagnetic wave, show that the average energy density of the E field equals the average energy density of the B field.

Ans : Comp 2019

Electromagnetic waves carry energy as they travel through space. Energy density of an E.M. wave is the energy in unit volume of the space through which the wave travels.

In free space, the energy density of a static field E is,

$$u_E = \frac{1}{2}\varepsilon_0 E^2$$

Again in free space, the energy density of a static magnetic field is,

$$\mu_B = \frac{1}{2\mu_0} B^2$$

The total energy density of the static electric and magnetic fields will be,

$$u = u_E + u_B$$
$$= \frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2\mu_0} B^2$$

But in an electromagnetic wave, both E and B fields very sinusoidally in space and time. The average energy density u of E.M. wave can be obtained by replacing E and B by their R.M.S. values in the above equation. Thus,

$$u = \frac{1}{2}\varepsilon_0 E_{\text{rms}}^2 + \frac{1}{2\mu_0} B_{\text{rms}}^2$$
$$= \frac{1}{4}\varepsilon_0 E_0^2 + \frac{1}{4\mu_0} B_0^2$$
$$\left[\text{since, } E_{\text{rms}} = \frac{E_0}{\sqrt{2}}, B_{\text{rms}} = \frac{B_0}{\sqrt{2}}\right]$$

Moreover, $E_0 = cB_0$

and $c^2 = \dfrac{1}{\mu_0 \varepsilon_0}$

Therefore, $u_E = \dfrac{1}{4}\varepsilon_0 E_0^2 = \dfrac{1}{4}\varepsilon_0 (cB_0)^2$

$$= \frac{1}{4}\varepsilon_0 \cdot \frac{B_0^3}{\mu_0 \varepsilon_0} = \frac{1}{4\mu_0} B_0^2 = u_B$$

Hence, in an electromagnetic wave, the average energy of the E field equals the average energy density of the B field. It may be noted that,

$$u = \frac{1}{4}\varepsilon_0 E_0^2 + \frac{1}{4}\varepsilon_0 E_0^2$$
$$= \frac{1}{2}\varepsilon_0 E_0^2 = \varepsilon_0 E_{\text{rms}}^2$$

Also, $u = \dfrac{1}{4\mu_0} B_0^2 + \dfrac{1}{4\mu_0} B_0^2$

$$= \frac{1}{2\mu_0} B_0^2 = \frac{1}{\mu_0} B_{\text{rms}}^2$$

135. Is a displacement current associated with a magnetic field? Or, can a changing electric flux induce a magnetic field? Explain it with the help of an example.

Ans : SQP 2021, 2018

A displacement current produces the same physical effects as the conduction current. Like a conduction current, a displacement current is also associated with a magnetic field. Consider, for example, the charging of a parallel plate capacitor by a constant current I in the connecting wires [Figure (a)]. This increases the charges on the capacitor plates at a steady rate. Consequently,

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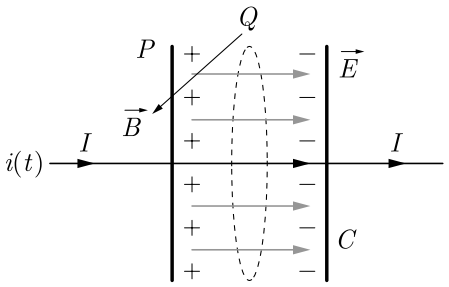
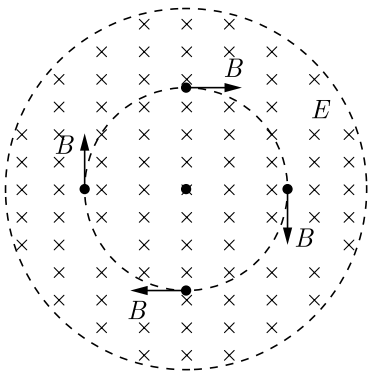
the electric field between the plates also increases at a steady rate. Between the capacitor plates, there exists a displacement current due to time varying electric field.



(a)



(b)

(a) Electric and magnetic fields $\vec{E}$ and $\vec{B}$ at any point Q between the capacitor plates. (b) A cross-sectional view of figure (a)

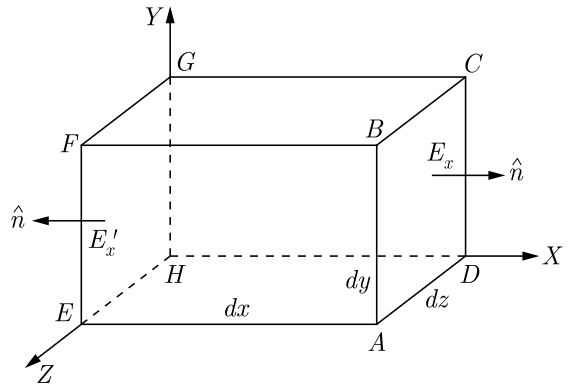
In such a region, we expect a magnetic field though there is no source of conduction current nearby. Experiments have shown that a magnetic field $\vec{B}$ is indeed induced (say at a point Q) between the capacitor plates and has same magnitude as that just outside (say at point P).

In Figure (a), the direction of $\vec{E}$ is from the positive plate to the negative, whereas the direction of $\vec{B}$ at Q is perpendicular to the plane of paper. Figure (b) shows a cross-sectional loop parallel to the plane of the plates. The field $\vec{E}$ is directed normally into the plane paper, as shown by crosses. The induced field $\vec{B}$ is clockwise along the tangents on a circle in this cross-sectional plane.

136. Prove mathematically that electromagnetic waves are transverse in nature.

Ans : **SQP 2016**

Consider a plane electromagnetic wave travelling in the X-direction. The associated wave-front lies in the YZ-plane and $ABCD$ is a portion of it at any time t. The electric and magnetic fields at time t will be zero to the right of $ABCD$. To the left of $ABCD$, they depend on x and t.



Consider the closed surface enclosed by the parallelepiped $ABCDEFGH$ of sides dx, dy and dz. The total electric flux through this closed surface must be zero as it does not enclose any charge.

By Gauss's theorem,

$$\oint_{ABCDEFGH} \vec{E} \cdot \vec{dS} = 0$$

$$\left[\oint_{ABCD} \vec{E} \cdot \vec{dS} + \oint_{EFGH} \vec{E} \cdot \vec{dS}\right] + \left[\oint_{ABFE} \vec{E} \cdot \vec{dS} + \oint_{DCGH} \vec{E} \cdot \vec{dS}\right] + \left[\oint_{AEHD} \vec{E} \cdot \vec{dS} + \oint_{BFGC} \vec{E} \cdot \vec{dS}\right] = 0$$

The paired integrals are the contributions from the faces normal to X, Y and Z-axis, respectively. Since E does not depend on y and z, the contributions from the faces normal to Y and Z-axis cancel out in pairs, so the above equation becomes,

$$\oint_{ABCD} \vec{E} \cdot \vec{dS} + \oint_{EFGH} \vec{E} \cdot \vec{dS} = 0 \qquad ...(1)$$

Let, E_x and E_x' be the x components of the electric field at the faces $ABCD$ and $EFGH$ respectively. The outward normals on these faces are oppositely directed (along X-axis), therefore,

$$\oint_{ABCD} \vec{E} \cdot \vec{dS} = E_x \cdot dy\, dz$$

$$\oint_{EFGH} \vec{E} \cdot \vec{dS} = -E_x' \, dy\, dz$$

Hence, Eq. (1) becomes

$$E_x \cdot dy\, dz - E_x' \cdot dy\, dz = 0$$

or $$E_x = E_x'$$

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i.e., the component of the electric field along the direction of propagation is constant. But a constant or static field cannot produce a wave, so this constant must be equal to zero, i.e., $E_x = 0$.

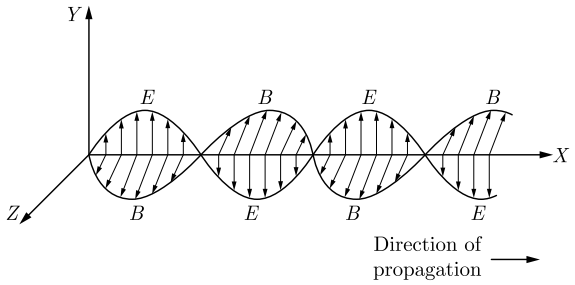
Similarly, we can prove that $B_x = 0$. Thus the electric or magnetic fields have no component along the direction of propagation. Or, in an electromagnetic wave both the electric and magnetic fields are perpendicular to the direction of propagation, i.e., the electromagnetic waves are transverse in nature.

137. What is an electromagnetic wave? How can we express mathematically a plane electromagnetic wave propagating along X-axis? Also represent it graphically.

Ans : **Comp 2020, 2017**

An electromagnetic wave is a wave radiated by an accelerated charge and which propagates through space as coupled electric and magnetic fields, oscillating perpendicular to each other and to the direction of propagation of the wave.

Mathematical Representation of Electromagnetic Waves



A plane electromagnetic wave travelling along X-axis

Above figure shows a plane electromagnetic wave of frequency ν and wavelength λ travelling along X-axis with speed c. The electric field $\vec{E}$ oscillates along Y-axis while the magnetic field $\vec{B}$ oscillates along Z-axis. The electric field vector can be represented mathematically as follows:

$$\vec{E} = E_y\hat{j} = E_0\sin(kx - \omega t)\,\hat{j}$$
$$= E_0\sin\left[2\pi\left(\frac{x}{\lambda} - \nu t\right)\right]\hat{j}$$
$$= E_0\sin\left[2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right)\right]\hat{j} \qquad ...(1)$$

where, $k = \dfrac{2\pi}{\lambda}$

is the propagation constant of the wave

and $\omega = 2\pi\nu$

Hence, $E_x = E_z = 0$

The magnetic field vector may be represented as,

$$\vec{B} = B_z\hat{k} = B_0\sin(kx - \omega t)\,\hat{k}$$
$$= B_0\sin\left[2\pi\left(\frac{x}{\lambda} - \nu t\right)\right]\hat{k}$$
$$= B_0\sin\left[2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right)\right]\hat{k} \qquad ...(2)$$

Hence, $B_x = B_y = 0$

Here, E_0 and B_0 are the amplitudes of the electric field $\vec{E}$ and magnetic field $\vec{B}$, respectively. They are related as,

$$\frac{E_0}{B_0} = c$$

The Eq. (1) and (2) show that the variations in electric and magnetic fields are in same phase.

As the electric and magnetic fields in an electromagnetic. wave are always perpendicular to each other and also perpendicular to the direction of wage propagation, so electromagnetic. waves are transverse in nature.

Maxwell showed that the speed of an electromagnetic wave in free space is given by,

$$c = \frac{1}{\sqrt{\mu_0\varepsilon_0}} = 3.0 \times 10^8\ \text{ms}^{-1}$$

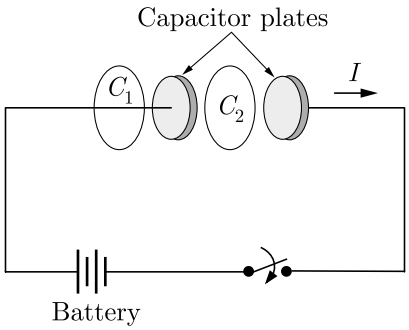
which is the speed of light in vacuum. This fact led Maxwell to predict that light is an electromagnetic wave.

138. State and explain Maxwell's modification of Ampere's circuital law.

Ans : **Main 2025**

According to Ampere's circuital law, the line integral of the magnetic field $\vec{B}$ along any closed loop C is proportional to the current I passing through the closed loop, i.e.,

$$\oint_C \vec{B}\cdot\vec{dl} = \mu_0 I \qquad ...(1)$$



(a)

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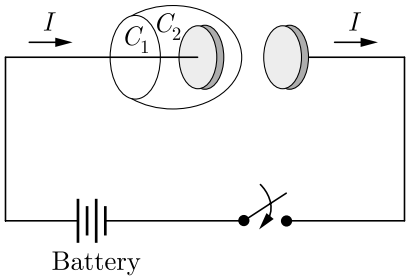

(b)

A parallel plate capacitor being charged by a battery

In 1864, Maxwell showed that the Eq. (1) is logically inconsistent. Consider a parallel plate capacitor being charged by a battery, as shown in figure (a). As the charging current I flows, a magnetic field is set up around the capacitor.

Now, the current I flows across the area bounded by loop C_1. Therefore,

$$\oint_{C_1} \vec{B} \cdot \vec{dl} = \mu_0 I \qquad ...(2)$$

But the are bounded by C_2 lies in the region between the capacitor plates, so no current flows across it.

Hence, $$\oint_{C_2} \vec{B} \cdot \vec{dl} = 0 \qquad ...(3)$$

Imagine the loops C_1 and C_2 to be infinitesimally close to each other, as shown in figure (b). Then we must have,

$$\oint_{C_1} \vec{B} \cdot \vec{dl} = \oint_{C_2} \vec{B} \cdot \vec{dl}$$

This result is inconsistent with the Eq. (2) and (3). There must be some missing term in this law.

Maxwell's Modification of Ampere's Law

Maxwell argued that a changing electric field between the capacitor plates must induce a magnetic field. As currents are the usual sources of magnetic fields, a changing electric field must be associated with a current. Maxwell called this current as the displacement current.

If, A be the area of the capacitor plates and q be the charge on the plates at any instant t during the charging process, then the electric field in the gap will be,

$$E = \frac{\sigma}{\varepsilon_0} = \frac{q}{\varepsilon_0 A}$$

$$EA = \frac{q}{\varepsilon_0}$$

Flux, $$\phi_E = \frac{q}{\varepsilon_0}$$

Hence, $$\frac{d\phi_E}{dt} = \frac{d}{dt}\left(\frac{q}{\varepsilon_0}\right) = \frac{1}{\varepsilon_0}\frac{dq}{dt}$$

But $\frac{dq}{dt}$ is the rate of change of charge on the capacitor plates. It is called displacement current and is given by,

$$I_d = \frac{dq}{dt} = \varepsilon_0 \frac{d\phi_E}{dt}$$

This is the missing term in Ampere's circuit law. The total current must be the sum of the conduction current I_c and the displacement current I_d. Thus,

$$I = I_c + I_d = I_c + \varepsilon_0 \frac{d\phi_E}{dt}$$

Hence, the modified form of the Ampere's law is,

$$\oint_C \vec{B} \cdot \vec{dl} = \mu_0 \left[I_c + \varepsilon_0 \frac{d\phi_E}{dt} \right]$$

NUMERICAL QUESTIONS

139. How long would gamma radiation take to travel from the Sun to the Earth, a distance of 1.5×10^{11} m ?

Ans : SQP 2016, 2014

Speed of γ-radiation is $c = 3 \times 10^8$ m/s

$$\text{distance} = 1.5 \times 10^{11} \text{ m}$$

Time taken by γ-radiation to travel from the Sun to the Earth is given by

$$\text{Time} = \frac{\text{Distance}}{\text{Velocity}}$$

$$= \frac{1.5 \times 10^{11}}{3 \times 10^8}$$

$$= 5 \times 10^2 \text{ s}$$

140. In an electromagnetic wave, the electric and magnetic fields are 100 V-m^{-1} and 0.265 A-m^{-1}. What is the maximum energy flows ?

Ans : Comp 2018

Intensity of electric field,

$$E_0 = 100 \text{ V-m}^{-1}$$

and intensity of magnetic field,

$$H_0 = 0.625 \text{ A-m}^{-1}$$

The maximum energy flow,

$$S = E_0 \times H_0$$

$$= 100 \times 0.265$$

$$= 26.5 \text{ W-m}^2$$

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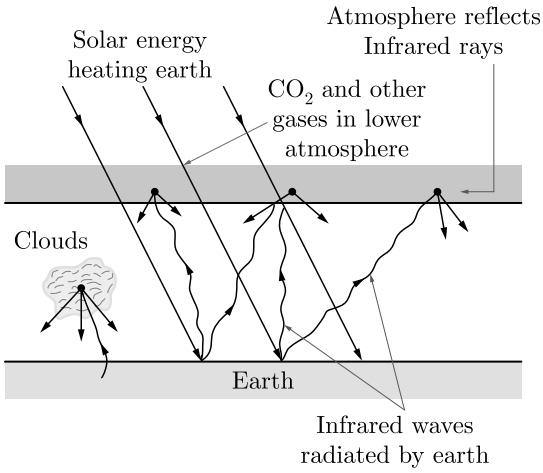
123. What is Greenhouse effect for the atmosphere of the earth and what is its importance?

Ans : **Main 2016**

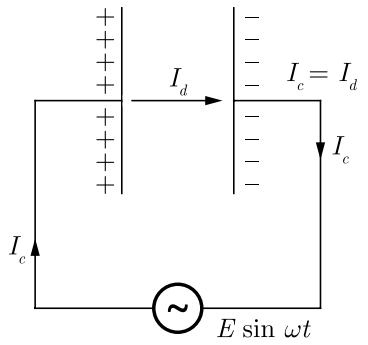
This is the phenomenon which keeps the earth's surface warm at night.



The radiation from the sun heats up the earth. Due to its lower temperature, the earth re-radiates it mostly in the infrared region. These infrared radiations cannot pass through the lower atmosphere, they get reflected back by gas molecules. Low lying clouds also reflect them back to the earth. These radiations heat up the objects on the earth's surface and so keep the earth's surface and so keep the earth's surface warm at night.

124. When an ideal capacitor is charged AC by a DC battery, no current flows. However, when an AC source is used, the current flows continuously. How does one explain this, based on the concept of displacement current ?

Ans : **Main 2010**



Ideal capacitor means infinite resistance for DC when an AC source is used, the current flow continuously, but we know that the capacitor has dielectric (air) between its plates. So, there is no current and circuit would be incomplete. In real capacitor is charged due to contribution of varying electric field. The current between the capacitor plates is given by displacement current.

$$D = \varepsilon E$$

$$I_d = \varepsilon \frac{d\phi}{dt}$$

125. Write the generalised expression for the Ampere's circuital law in terms of the conduction current and the displacement current. Mention the situation when there is

(i) only conduction current and no displacement current.

(ii) only displacement current and no conduction current.

Ans : **SQP 2013**

Generalised Ampere's circuital Law :

The equation of the generalised Ampere's circuital Law is as follows :

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 I_C + \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}$$

According to this law line integral of magnetic field over closed loop is equal to μ_0 times sum of conduction current and displacement current.

(i) In case of steady electric field in a conducting wire, electric field does not change with time, conduction current exists in the wire but displacement current may be zero.

So, $\oint \vec{B} \cdot \vec{dl} = \mu_0 I_C$

(ii) In large region of space, where there is no conduction current, but there is only a displacement current due to time varying electric field (or flux).

So, $\phi \vec{B} \cdot \vec{dl} = \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}$

126. Describe very briefly and four regions of electromagnetic spectrum mentioning their special properties/features.

Ans : **Main 2002, 2000**

The distribution of electromagnetic radiations according to their wavelength or frequency is called the electromagnetic spectrum.

Four regions of electromagnetic spectrum are

(i) X-rays

(ii) Infrared rays

(iii) Ultraviolet rays

(iv) γ-rays

NODIA

(iv) In the electromagnetic spectrum which radiation has maximum wavelength and maximum frequency?

(v) Which parts of the electromagnetic spectrum is not visible by our eye?

Ans :

(i) The visible spectrum was discovered by Newton.

(ii) 4×10^{-7} m in the violet region to 8×10^{-7} m in the red region.

(iii) Radiowave has the maximum wavelength from the electromagnetic spectrum.

(iv) Radiowave has the maximum wavelength from the electromagnetic spectrum and gamma rays has the maximum frequency.

(v) Except the visible spectrum all the radiation from the electromagnetic spectrum is not visible by our eye.

145. Seema noticed that some scientists have predicted that a global nuclear war on the Earth would be followed by a server 'nuclear winter' (Nuclear winter is the term for a theory describing the climatic effects of nuclear war.) with devastating effect on life on the Earth. She was interested to know the facts and so she went to her friend Reema. Reema explained him all the concerning facts properly.

(a) What is the effect of a nuclear winter?

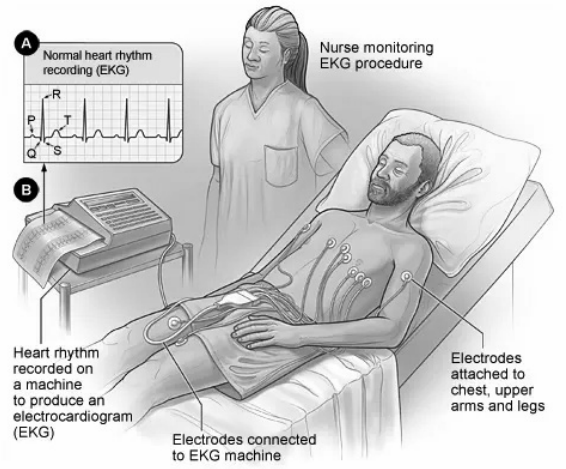
(b) What might be the basis of this prediction ?

Ans :

(a) The conditions of semi-darkness, killing frosts and sub-freezing temperatures, combined with high doses of radiation from nuclear fallout, would interrupt plant photosynthesis and could thus destroy much of the Earth's vegetation and animal life.

(b) A global nuclear war would make the substantial parts of the sky getting covered by very minute particles. They will be responsible for preventing Sun rays from reaching the Earth for a very long time resulting in 'nuclear winter'.

146. Kavita's anut was advised by her doctor to have an ECG (Electrocardiograph) for heart. Her aunt did not know much about the details and significance of this test. She also felt that it was too expensive and thought of postponing it. When Kavita learnt about her aunt's problem, she took the help of her parents, friends and responsible neighbours and arranged for the cost of test. Then she told her aunt that an ECG of heart would enable the doctor to know the condition of her heart without causing any harm to her. Her aunt was convinced and got the required ECG of her heart done. The resulting information greatly helped her doctors to treat her well.



(a) What do you mean by ECG?

(b) A plane electromagnetic wave of frequency 25 MHz travels in free space along the x -direction. At a particular point space and time, the electric vector $\overline{E} = 6.3\ \text{V/m}\,\hat{j}$. Calculate B at this point.

Ans :

(a) An electrocardiogram (ECG) is a simple test that can be used to check your heart's rhythm and electrical activity. Sensors attached to the skin are used to detect the electrical signals produced by your heart each time it beats.

(b) In given condition, magnetic vector $\vec{B}$ must be along z-axis with,

$$B_0 = \frac{E_0}{c}$$

$$= \frac{6.3}{3 \times 10^8}$$

$$= 2.1 \times 10^{-8}\ \text{T}$$

Thus, $B = 2.1 \times 10^{-8}\ \text{T}\,\hat{k}$

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(Minus sign due to object placed in front of mirror)

Relation for the distance of image from pole of the convex mirror v is:

$$\frac{1}{f}=\frac{1}{v}+\frac{1}{u}=\frac{1}{v}+\frac{1}{(-f)}$$

$$\frac{1}{v}=\frac{1}{f}+\frac{1}{f}=\frac{2}{f}$$

$$v=\frac{f}{2}$$

Thus (c) is correct option.

24. The velocity of light in a medium is $2\times10^8\,\text{m}(-)\text{s}^{-1}$. Refractive index of the medium is

(a) 1 (b) 1.1

(c) 1.4 (d) 1.5

Ans : Main 2011, 2005

Given,

Velocity of light in medium,

$$v=2\times10^8\,\text{m}(-)\text{s}^{-1}$$

refractive index of the medium,

$$\mu=\frac{c}{v}=\frac{3\times10^8}{2\times10^8}=1.5$$

(where, $c=$ velocity of light equal to $3\times10^8\,\text{m}-\text{s}^{-1}$)

Thus (d) is correct option.

25. The magnifying power of a magnifying glass of power 12 dioptre is

(a) 4 (b) 1200

(c) 3 (d) 25

Ans : Main 2025, 2012

Given,

Magnifying power of glass $=12$

Power of the lens, $P=\frac{1}{f}$

$$f=\frac{1}{P}=\frac{1}{12}\,\text{m}=\frac{100}{12}\,\text{cm}$$

Magnifying lower of simple microscope is given by,

$$m=1+\frac{D}{f}$$

$$=1+\frac{25\times12}{100}=1+3=4$$

Thus (a) is correct option.

26. An object is kept on the principal axis of a concave mirror of focal length 10 cm, at a distance of 15 cm from its pole. The image formed by the mirror is

(a) virtual and magnified

(b) virtual and diminished

(c) real and magnified

(d) real and diminished

Ans : Main 2018

$$u>f \qquad \text{(but less than } 2f\text{)}$$

$$v>2f \text{ and } |m|>1$$

Thus, when the object lies between the focus and centre of curvature, a real, inverted and magnified image is formed beyond the centre of curvature of the concave mirror.

Thus (c) is correct option.

27. When a light wave travels from air to glass

(a) its wavelength decreases.

(b) its wavelength increases.

(c) there is no change in wavelength

(d) its frequency decreases.

Ans : Main 2017

Its wavelength decreases because they are related by the formula,

$$\mu=\frac{\lambda_{\text{vac}}}{\lambda_{\text{med}}}$$

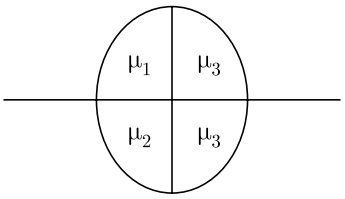
Here, $$\mu=\frac{\lambda_{\text{air}}}{\lambda_{\text{glass}}}$$

as velocity in medium decreases hence its wavelength decreases,

$$v=v\lambda$$

Thus (a) is correct option.

28. How many images are formed by the lens if an object is kept on its axis?



(a) 1 (b) 2

(c) 3 (d) 7

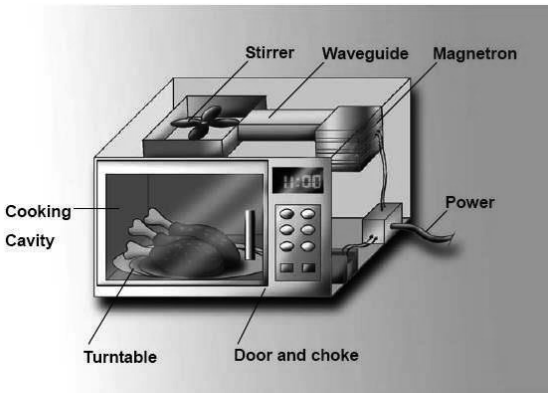
Ans : Main 2013

Mediums of refractive index μ_1 and μ_3 will form one lens and mediums of refractive Index μ_2 and μ_3 will form other lens both will have different focal length, so two images will be formed of an object.

Thus (b) is correct option.

NODIA

household activities. She requested her aunt and convinced her about details and significance of microwave oven .



(a) Why wave-guide is used in microwave frequency ?

(b) How does microwave oven work ? Explain briefly.

Ans :

(a) Wave-guides are used at frequencies in the microwave range. At microwave frequencies (above 1GHz to 100 GHz) the losses in the two line transmission system will be very high and hence it cannot be used at those frequencies. Hence microwave signals are propagated through the wave-guides in order to minimize the losses.

(b) Microwave oven works because microwaves of a particular wavelength are very strongly absorbed by water. The energy carried by the microwaves heats the water up. Generally all food items contain a lot of water, they can be heated and cooked very quickly in microwave oven. In this way the microwaves heat the food item throughout its volume, not just from the outside as in a normal oven.

****

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12. When two converging lenses of same focal f are placed in contact, the focal length of the combination is

(a) f (b) $2f$

(c) $\frac{f}{2}$ (d) $3f$

Ans : SQP 2015

Focal length of combination of lens is given by

$$\frac{1}{f_{eq}} = \frac{1}{f_1} + \frac{1}{f_2}$$

Here, $f_1 = f_2 = f$

Then, $$\frac{1}{f_{eq}} = \frac{1}{f} + \frac{1}{f}$$

$$\frac{1}{f_{eq}} = \frac{1+1}{f}$$

$$f_{eq} = \frac{f}{2}$$

Thus (c) is correct option.

13. The focal length of a lens $\mu = 1.5$ in air is 20 cm. Its focal length in medium of refractive index 1.5 is

(a) 20 cm (b) 40 cm

(c) 10 cm (d) ∞

Ans : SQP 2017

When lens is placed in medium, then

$$\frac{1}{f} = ({}^{m}\mu_g - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\frac{1}{f} = \left(\frac{\alpha_g}{\alpha_m} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

where, $\mu_g = \mu_m = 1.5$

Hence, $\frac{1}{f} = 0$

$$f = \infty$$

Thus (d) is correct option.

14. Which of the following phenomena taken place when a monochromatic light is incident on a prism?

(a) Dispersion (b) Deviation

(c) Interference (d) All of these

Ans : Main 2018

When monochromatic light passes through a prism, it bends due to refraction. This bending is called deviation. Dispersion does not occur because monochromatic light contains only one colour. Interference also does not occur in this case. Hence, only deviation takes place.

Thus (a) is correct option.

15. An object is immersed in a fluid. In order that the object becomes invisible, it should

(a) have refractive index one

(b) absorb all light falling on it

(c) behave as a perfect reflector

(d) have refractive index exactly matching with that of the surrounding fluid

Ans : Comp 2010

If refractive index of a material is exactly matching with that of the surrounding fluid, then no refraction or reflection takes place on their surface of separation and the object becomes invisible.

Thus (d) is correct option.

16. If the critical angle for a medium is 45°, then its refractive index will be

(a) $\sqrt{2}$ (b) $\frac{\sqrt{3}}{2}$

(c) $\frac{2}{\sqrt{3}}$ (d) $\frac{1}{\sqrt{2}}$

Ans : SQP 2017

Given,

Critical angle of the medium,

$$C = 45^\circ$$

Refractive index of the medium,

$$\mu = \frac{1}{\sin C} = \frac{1}{\sin 45^\circ}$$

$$= \frac{1}{1/\sqrt{2}} = \sqrt{2}$$

Thus (a) is correct option.

17. The refractive indices of water and glass are 1.2 and 1.5 respectively. What will be the refractive index of glass with respect to water ?

(a) 1.75 (b) 1.25

(c) 0.8 (d) 0.6

Ans : Main 2009

Refractive index of water,

$$\mu_w = 1.2$$

and refractive index of glass,

$$\mu_g = 1.5$$

Refractive index of glass with respect to water,

$${}^{w}\mu_g = \frac{\alpha_g}{\alpha_w} = \frac{1.5}{1.2} = 1.25$$

Thus (b) is correct option.

NODIA

Mirror Formula

Mirror Formula is $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

where, f = focal length of mirror

u = object distance

v = image distance

Lens Formula

Lens formula is $\frac{1}{f} = \frac{1}{u} - \frac{1}{v}$ and Lens maker's formula is the relation between the radii of curvatures R_1, R_2 of the curved surfaces of lens, then if f is the focal length of the lens, then

$$\frac{1}{f} = (\mu - 1)\left\{\frac{1}{R_1} - \frac{1}{R_2}\right\}$$

In our eye lens, we change its focal length by changing the radius of two sides of eye lens by the action of ciliary muscles and zinule fibres.

5. LINEAR MAGNIFICATION OF THE IMAGE

The radio of the height of image and the ratio of height of object is knower ass linear magnification. i.e.

$$m = \frac{v}{u}$$
$$= \frac{f}{f+u} = \frac{f-v}{f}$$

6. POWER OF A LENS

Power of a lens is the reciprocal of its focal length. Power is measured in dioptre (D).

$$\text{Power (in dioptre)} = \frac{1}{f(\text{in metre})}$$

Power are added algebraically

$$P = P_1 + P_2 + P_3 ..... + P_n$$

7. WHEN LENSES ARE COMBINED

When lenses are combined together side to side (touching) then combined focal lengths f is,

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{1}{f_3} + ... + \frac{1}{f_n}$$

8. THE RESULTANT FOCAL LENGTH

The resultant focal length f of combination of two lens of focal lengths f_1 and f_2 placed distance x apart is

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{1}{f_1 f_2}$$

and their combined power is

$$P = P_1 + P_2 - xP_1P_2$$

9. PRISM

Prism is a portion of transparent medium like glass, quartz, rock slat etc. bounded by three rectangular and two triangular plane surfaces.

For a prism,

1. $A + \delta = i + e$:
2. $\delta = A(\mu - 1)$ if angles are small
3. $\mu = \frac{\sin\frac{A+\delta_m}{2}}{\sin\frac{A}{2}}$

where, δ = deviation angle

i = incidence angle

e = emergent angle

μ = refractive index of prism

A = prism angle

10. DISPERSION

Dispersion is the phenomenon of splitting up of white light into constituent colours when passed through prism. Dispersion is due to different refractive index μ for different wavelengths.

According to Cauchy's law

$$\mu = a + \frac{b}{\lambda^2} + \frac{c}{\lambda^4}$$

and $$\delta = A(\mu - 1)$$

More the λ, lesser the μ and lesser deviation δ for ray as compared to violet ray.

Angle of dispersion,

$$\theta = \delta_v - \delta_r = (\alpha_v - \alpha_r)A$$

Dispersing power, $\omega = \frac{\theta}{\text{mean deviation } \delta}$

$$= \frac{\alpha_v - \alpha_r}{\alpha - 1}$$

11. ANGULAR DISPERSIVE POWER

Angular dispersive power is the angle of dispersion per unit wavelength range. If $d\delta$ is the angel of dispersion between wavelength range λ and $\lambda + d\lambda$(range of $d\lambda$), then angular dispersive power

$$\omega = \frac{d\delta}{d\lambda}$$

It can be proved that $\omega \propto \frac{1}{\lambda^3}$.

This shown that spectrum is more spread on the short wavelength side (violet) than on the long wavelength side (red).

Hence prism spectrum is not linear.

NODIA

147. Mohit fractured his leg by chance while playing. His parents took him to a doctor for treatment. The doctor advised that an X-rays of the leg needed to be done for diagnosing the problem. On seeing X-rays photograph. Mohit was amazed and excited to know that the photograph was so clear. He requested the doctor to explain how it happened. The doctor gave a brief explanation of his question happily and appreciated Mohit's nature.

(a) Which property of X-rays make it suitable for use in diagnosing and identifying the fracture in bones ?

(b) Write two other uses of X-rays ?

Ans :

(a) The property of X-rays to resiny pass through flesh but unable to pass through bones is used to take X-rays photograph.

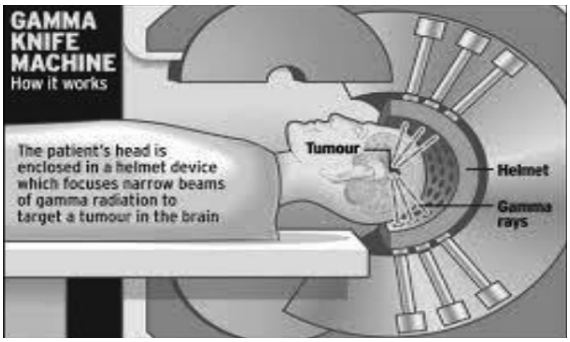
(b) Two other uses of X-ray are :

(i) Study of crystal structures.

(ii) In engineering-for detecting cracks, faults etc.

148. A gamma ray (g) is a packet of electromagnetic energy (photon) emitted by the nucleus of some radionuclide following radioactive decay. Gamma photons are the most energetic photons in the electromagnetic spectrum. Gamma rays are a form of electromagnetic radiation (EMR). They are the similar to X-rays, distinguished only by the fact that they are emitted from an excited nucleus. Electromagnetic radiation can be described in terms of a stream of photons, which are massless particles each travelling in a wave-like pattern and moving at the speed of light. Each photon contains a certain amount (or bundle) of energy, and all electromagnetic radiation consists of these photons. Gamma-ray photons have the highest energy in the EMR spectrum and their waves have the shortest wavelength. Gamma-ray photons generally have energies greater than 100 keV. For comparison, ultraviolet radiation has energy that falls in the range from a few electron volts to about 100 eV and does not have enough energy to be classified as ionising radiation. The high energy of gamma rays enables them to pass through many kinds of materials, including human tissue. Very dense materials, such as lead, are commonly used as shielding to slow or stop gamma rays.

Gamma rays are used in radiotherapy to Treat cancer. They are used to spot tumours, they kill the living cells and damage malignant tumour.


GAMMA KNIFE MACHINE
How it works
The patient's head is enclosed in a helmet device which focuses narrow beams of gamma radiation to target a tumour in the brain
Tumour
Helmet
Gamma rays

(a) What is the source of gamma rays ?

(b) How is wavelength of gamma rays ?

(c) What is the correct order of alpha, beta and gamma rays according to the wave length ?

Ans :

(a) Radioactive decay of nucleus.

(b) High.

(c) Gamma $>$ beta $>$ alpha.

149. Microwave oven, also called electronic oven, appliance that cooks food by means of high-frequency electromagnetic waves called microwaves. A microwave oven is a relatively small, boxlike oven that raises the temperature of food by subjecting it to a high-frequency electromagnetic field. The microwaves are absorbed by water, fats, sugars, and certain other molecules, whose consequent vibrations produce heat. The heating thus occurs inside the food, without warming the surrounding air; this greatly reduces cooking time, and baking and other cooking tasks that require hours in a conventional oven can be completed in minutes in a microwave oven. Microwave ovens generate radiation at a frequency of about 2,450 megahertz by means of a magnetron, which is a kind of electron tube.

Monika wanted to gift her aunt a microwave oven so that her aunt enjoys some rest from tough

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4. The radius of curvature of plane mirror is

(a) infinite (b) zero

(c) $+5$ cm (d) -5 cm

Ans : SQP 2011

As we know that a plane mirror is a part of sphere of infinite focal length. So its radius of curvature is infinite

$$[\because\ r = 2f].$$

Thus (a) is correct option.

5. If a glass rod is immersed in a liquid of the same refractive index, then it will

(a) disappear (b) look bent

(c) look longer (d) look shorter

Ans : Main 2007

We know that if a glass rod is will immersed in a liquid of the same refractive index as that of the rod, then no refraction will take place.

Therefore, the glass rod will disappear.

Thus (a) is correct option.

6. SI unit of power of a lens is

(a) joule (b) dioptre

(c) candela (d) watt

Ans : Main 2011

The reciprocal of focal length f is known as the power of the lens. i.e.,

Power of lens, $P = \dfrac{1}{f(\text{focal length})}$

The SI unit of power of lens is dioptre.

Thus (b) is correct option.

7. A plane mirror products a magnification of

(a) 0

(b) -1

(c) $+1$

(d) between 0 and $+1$

Ans : Main 2009

In a plane mirror, height of image formed is erect and of the same size as of the object i.e.,

$$h_2 = h_1 \quad (\text{where, } h_1 = \text{size of object})$$

Therefore magnification of plane mirror,

$$m = +\frac{h_2}{h_1}$$

$$= +\frac{h_1}{h_1} = +1$$

Thus (c) is correct option.

8. The final image in astronomical telescope is

(a) real and erect (b) real and inverted

(c) virtual and inverted (d) virtual and erect

Ans : Main 2016

An astronomical telescope is an optical instrument which is used to see the magnified image of distant heavily bodies like stars planets , satellites and galaxies etc. The final image formed by an astronomical telescope is always virtual, inverted and magnified.

Thus (c) is correct option.

NODIA

Two thin lenses having optical powers of –8 D and +12 D are placed in contact with each other. The focal length of this combination is

(a) + 0.25 m (b) – 0.25 m

(c) + 0.25 cm (d) – 0.25 cm

Ans : Main 2023

Given, $P_1 = -8\,\text{D},\ P_2 = 12\,\text{D}$

$$P = P_1 + P_2 = -8 + 12$$

$$P = 4$$

$$F = \frac{1}{P} = \frac{1}{4} = 0.25\,\text{m}$$

Thus (a) is correct option.

10. When the tube length of microscope is increased its magnifying power

(a) increases

(b) decreases

(c) becomes zero

(d) remains unchanged

Ans : Main 2016

Tube length of microscope is directly proportional to magnifying power of microscope. When the tube length of microscope is increased, its magnifying power will be increases. Thus (a) is correct option.

11. A convex lens, made of glass, is immersed in water. As a result, its focal length will

(a) increase (b) decrease

(c) double (d) remain same

Ans : SQP 2018

When a convex lens made up of glass is immersed in water, then due to change in refractive index, focal length of the lens changes. Since water is less denser than glass i.e., refractive index of liquid is less than the refractive index of material of lens, so the focal length increases.

Thus (a) is correct option.

CHAPTER 9

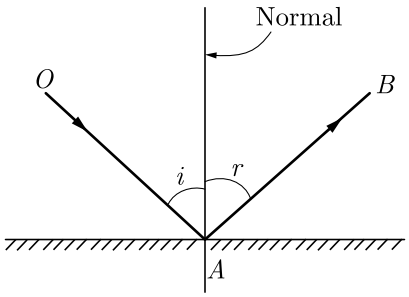
Ray Optics & Optical Instruments

SUMMARY

1. REFLECTION OF LIGHT

Reflection of light is the phenomenon of bouncing back of light in the same medium after striking a surface.

The reflection of light is shown in figure:



where, OA = incident ray

AB = reflected ray

$\angle i$ = incident angle

$\angle r$ = reflection angle

2. TOTAL INTERNAL REFLECTION

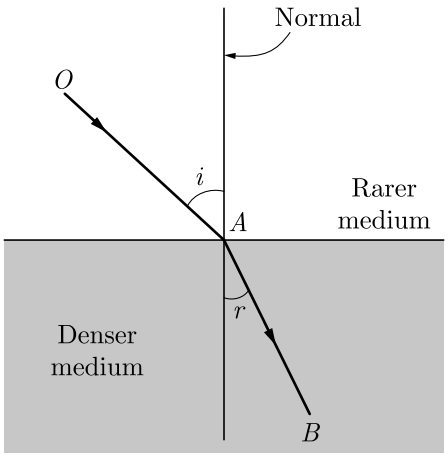
Critical angle is the angle of incidence in the denser medium for which angle of refraction in rarer medium is 90°.

When angle of incidence in the denser medium is greater than critical angle, the ray is reflected back in the denser medium. This phenomenon is called total internal reflection. In this case angle of incidence is equal to the angle of reflection.

Practical applications of total internal reflection are mirage, optical fibre, brilliance of a diamond.

3. REFRACTION

Refraction of light is the change in path of a ray of light a passes from one medium into another. Refraction of light follows two laws.



where, OA = incident ray

AB = reflected ray

NA = Normal

1st law : The incident ray, refracted ray and the normal at the point of incidence,all lie on the same plane.

2nd law : The ratio of sine of angle of incidence to the sine of angle of refraction is constant for any two given media.

i.e., $$\mu = \frac{\sin i}{\sin r}$$

Also, $${}^{a}\mu_{b} \times {}^{b}\mu_{c} \times {}^{c}\mu_{a} = 1$$

or $${}^{b}\mu_{c} = {}^{b}\mu_{a}\,{}^{a}\mu_{c} = \frac{{}^{a}\alpha_{c}}{{}^{a}\alpha_{b}}$$

Again, $$\mu = \frac{\text{Real Depth}}{\text{Apparent Depth}}$$

4. REFRACTION AT SPHERICAL SURFACES

When light travels from rarer to denser medium, then

$$\frac{\alpha_1}{-\alpha} + \frac{\alpha_2}{v} = \frac{\alpha_2 - \alpha_1}{R}$$

but when it travels from denser to rarer medium, then

$$\frac{\alpha_2}{-\alpha} + \frac{\alpha_1}{v} = \frac{\alpha_2 - \alpha_1}{R}$$

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18. Optical fibre communication is based on which of the following phenomena

(a) Total internal reflection

(b) Scattering

(c) Reflection

(d) Interference

Ans : SQP 2018

Optical fibre communication is based on total internal reflection. When light is incident on one end of the fibre at a small angle, it goes inside and suffers repeated total internal reflection because the angle of incidence is greater than the critical angle of the fibre material with respect to its outer coating.

Thus (a) is correct option.

19. When a ray of light enters a glass slab its wavelength

(a) decreases

(b) increases

(c) remains unchanged

(d) data are not complete

Ans : SQP 2016, 2015, 2013

As the light enters from rarer medium to the denser medium, the speed of light decreases but frequency remains same. The relation between speed of light, V wavelength λ and the frequency n is given as,

$$V = n\lambda$$

In the denser medium frequency, n remains constant and Velocity V decreases therefore wavelength, λ also decreases to keep the frequency constant. Thus (a) is correct option.

20. A convex lens is dipped in a liquid, whose refractive index is equal to refractive index of material of lens. Then its focal length will

(a) become zero (b) become infinite

(c) decrease (d) increase

Ans : Main 2018

We know that,

$$\frac{1}{f} = ({}_1\mu_2 - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\frac{1}{f} = \left(\frac{\alpha_2}{\alpha_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Here, $\mu_1 = \mu_2$

Then, $\frac{1}{f} = 0$ or $f = \infty$

Thus (b) is correct option.

21. If a ray of light is incident on a plane mirror at an angle of 30°, then deviation produced by the plane mirror is

(a) 30° (b) 60°

(c) 90° (d) 120°

Ans : SQP 2002, 2010

Given,

Angle of incidence $i = 30^\circ$

angle of reflection, r = Angle of incidence $i = 30^\circ$

We also know that deviation produced by plane mirror,

$$\begin{aligned}\delta &= 180^\circ - (i + r)\\ &= 180^\circ - (30^\circ + 30^\circ)\\ &= 180^\circ - 60^\circ\\ &= 120^\circ\end{aligned}$$

Thus (d) is correct option.

22. If ${}^m\mu_n$ represents refractive index when a light ray goes from medium m to medium n, then the value of the product ${}^2\mu_1 \times {}^3\mu_2 \times {}^4\mu_3$ is equal to

(a) ${}^3\mu_1$ (b) ${}^3\mu_2$

(c) ${}^4\mu_2$ (d) ${}^4\mu_1$

Ans : Main 2004

We know from the principle of reversibility that refractive index of medium,

$${}^m\mu_n = \frac{1}{{}^n\mu_m}$$

Therefore value of the product,

$$\begin{aligned}{}^2\mu_1 \times {}^3\mu_2 \times {}^4\mu_3 &= \frac{1}{{}^1\alpha_2} \times \frac{1}{{}^2\alpha_3} \times \frac{1}{{}^3\alpha_4}\\ &= \frac{1}{{}^1\alpha_2 \times {}^2\alpha_3 \times {}^3\alpha_4}\\ &= \frac{1}{{}^1\mu_4} = {}^4\mu_1\end{aligned}$$

...(where, ${}^i\mu_j \times {}^j\mu_k = {}^i\mu_k$)

Thus (d) is correct option.

23. An object is placed at a distance f in the front of a convex mirror. If focal length of the mirror is f, then distance of image from pole of the mirror is

(a) f (b) $2f$

(c) $\frac{f}{2}$ (d) $\frac{f}{4}$

Ans : SQP 2015

Focal length of convex mirror $= f$.

and distance between object and mirror,

$$u = -f$$

NODIA

12. RAYLEIGH'S LAW OF SCATTERING

Rayleigh's law of scattering is that scattering of light by air etc. is inversely proportional to the fourth power of wavelength i.e.

$$\text{Scattering} \propto \frac{1}{\lambda^4}$$

Blue colour of the sky, reddish colour of the sun at the time of sunrise and sunset can be explained on the basis of above said law.

13. OPTICAL INSTRUMENTS

Optical instruments are the instruments based upon laws of reflection and refraction.

14. MICROSCOPE

Microscope is an optical instrument used to observe minute particles in magnified form.

A simple microscope is an ordinary convex lens of small focal length placed at such a distance from object so that its clear image is formed at the least distance of distinct vision. It is used by biology students to observe dissected animal by watch repairer and by palmists. Its magnifying power,

$$M = \left(1 + \frac{D}{f_e}\right)$$

15. COMPOUND MICROSCOPE

Compound microscope consists of two lenses an objective of small aperture and small focal length.

16. MAGNIFYING POWER OF COMPOUND MICROSCOPE

1. When image formed at near point,

$$m = \frac{v_0}{u_0}(1 + Df_e)$$

2. When the final image is at infinity,

$$m = \frac{-C}{f_0} \cdot \frac{D}{f_e}$$

17. TELESCOPE

Telescope is used to study far off objects clearly. Astronomical telescope is used to observe heavenly bodies. It forms an inverted image. Its magnifying power in normal adjustment is,

$$M = -\frac{f_0}{f_e}$$

When the image of a distant object is formed at least distance of distinct vision, the magnifying power is,

$$M = -\frac{f_0}{f_e}\left(1 + \frac{f_e}{D}\right)$$

18. RESOLVING POWER

Resolving power of an optical instrument is its ability to resolve two images of two point objects lying very close to each of these so that other images can be seen quite separately and distinctly.

$$\text{R.P. of microscope} = \frac{2\mu \sin\theta}{\lambda}$$

and

$$\text{R.P. of telescope} = \frac{D}{1.22\lambda}$$

OBJECTIVE QUESTIONS

1. A ray of monochromatic light propagating in air is incident on the surface of water. Which of the following will be the same for the reflected and refracted rays?

(a) Energy carried (b) Speed

(c) Frequency (d) Wavelength

Ans : SQP 2023

The frequency of the light remains constant when it passes from one medium to another and it does not depend on the medium it passes through.

Thus (c) is correct option.

2. Dispersive power of a prism depends upon

(a) shape of the prism

(b) height of the prism

(c) material of the prism

(d) angle of the prism

Ans : Main 2022 Sem-II

The dispersive power of a prism depends on the nature of material of prism.

Thus (c) is correct option.

3. The image formed by objective lens of a compound Microscope is

(a) Virtual and diminished

(b) Real and diminished

(c) Real and large

(d) Virtual and Large

Ans : Main 2018

The image formed by objective lens of a compound microscope is real and large.

Thus (c) is correct option.

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29. A point object is placed at the centre of a glass sphere of radius 6 cm and refractive index 1.5. The distance of the virtual image from the surface of the sphere is

(a) 2 cm (b) 4 cm

(c) 6 cm (d) 12 cm

Ans : SQP 2012

Given,

Radius of sphere, $R = 6\,\text{cm}$

and, refractive index of glass,

$$\mu = 1.5$$

when rays from the object are incident normally on the surface of a sphere and emerge undeviated, then distance of the virtual image from the surface is equal to the radius of sphere i.e., 6 cm.

Thus (c) is correct option.

30. If red and violet light rays are of focal lengths f_R and f_V, then which of the following is true relationship?

(a) $\lambda_R < \lambda_V$ (b) $\propto_R < \propto_V$

(c) $\propto_R > \propto_V$ (d) $\lambda_R \leq \lambda_V$

Ans : Main 2017, 2012

Given,

$$\text{Focal length of red light} = f_R$$

and $$\text{focal length of violet light} = f_V$$

relation for focal length of the lens f is,

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$f \propto \frac{1}{\mu}$$

Since, $f_V < f_R$

Therefore, $\mu_R < \mu_V$

Thus (b) is correct option.

31. If the critical angle for total internal reflection, from a medium to vacuum is 30°, then velocity of light in the medium is

(a) $6 \times 10^8\,\text{m} - \text{s}^{-1}$ (b) $3 \times 10^8\,\text{m} - \text{s}^{-1}$

(c) $2 \times 10^8\,\text{m} - \text{s}^{-1}$ (d) $1.5 \times 10^8\,\text{m} - \text{s}^{-1}$

Ans : SQP 2004

Given,

Critical angle, $C = 30^\circ$

We know from the law of total internal reflection that velocity of light in the medium,

$$v = c \times \sin C = c \times \sin 30^\circ$$

$$= (3 \times 10^8) \times 0.5$$

$$= 1.5 \times 10^8\,\text{m} - \text{s}^{-1}$$

where, c = velocity of light equal to $3 \times 10^8\,\text{m} - \text{s}^{-1}$

Thus (d) is correct option.

32. In case of a regular prism, in minimum deviation position, angle made by the refracted ray (inside the prism) with the normal drawn to the refracting surface is

(a) 90° (b) 60°

(c) 45° (d) 30°

Ans : Main 2022 Sem-II

For a regular prism, the prism angle A = 60°. At minimum deviation position, the angle of refraction inside the prism is equal at both refracting surfaces.

$$r_1 = r_2 = A/2$$

Therefore, $= 60°/2 = 30°$

Hence, the refracted ray inside the prism makes an angle of 30° with the normal drawn to the refracting surface.

Thus (d) is correct option.

NODIA

33. Two thin lenses having optical power of – 10 D and + 6D are placed in contact with each other. The focal length of the combination is

(a) + 0.25 cm (b) – 0.25 cm

(c) + 0.25 m (d) – 0.25 m

Ans : Main 2024, 2005

$$P_1 = -10\,\text{D},\ P_2 = +6\,\text{D}$$

Power of combination of lens is given by

Let power, $P_3 = P_1 + P_2$

$$P_3 = -10 + 6 = -4\,\text{D}$$

Power of lens $P = \frac{1}{f(m)}$

$$-4 = \frac{1}{f}$$

$$f = -\frac{1}{4} = -0.25\,\text{m}$$

Thus (d) is correct option.

34. If an object is placed at a distance of 10 cm in front of a concave mirror of focal length 20 cm, the image formed will be

(a) real and 20 cm in front of the mirror

(b) real and 6.67 cm in front of the mirror

(c) virtual and 20 cm behind the mirror

(d) virtual and 6.67 cm behind the mirror

Angle of refraction, $r = 90^\circ$

Now, from Equation (1)

$$n_1 \sin\theta = n_2 \sin 90^\circ$$

$$\sin\theta = \frac{n_2}{n_1} \quad ...(2)$$

$$n = \frac{c}{v}$$

where n is inversely proportional to v.

Hence, $$\frac{n_2}{n_1} = \frac{v_1}{v_2}$$

$$\sin\theta = \frac{v_1}{v_2}$$

$$v_2 = \frac{v}{\sin\theta}$$

Thus (b) is correct option.

43. A sound wave travels from air to water. The angle of incidence is α_1 and the angle of refraction is α_2. If the Snell's law is valid, then

(a) $\alpha_1 > \alpha_2$ (b) $\alpha_1 < \alpha_2$

(c) $\alpha_1 = \alpha_2$ (d) $\alpha_1 = 90^\circ$

Ans : **Main 2024**

Angle of incidence, $i = \alpha_1$

Angle of refractions, $r = \alpha_2$

Refractive index of water with respect to air,

$$^a\mu_w = \frac{\text{Velocity of sound in air}}{\text{Velocity of sound in water}}$$

$$= \frac{v_a}{v_w} \quad ...(1)$$

We also know from the Snell's law that refractive index of water with respect to air,

$$^a\mu_w = \frac{\sin i}{\sin r} = \frac{\sin\alpha_1}{\sin\alpha_2} \quad ...(2)$$

Equating equations (1) and (2),

$$\frac{v_a}{v_w} = \frac{\sin\alpha_1}{\sin\alpha_2}$$

Since velocity of sound in water, v_w is greater than that of air v_a,

Therefore, $$\frac{v_a}{v_w} < 1$$

$$\frac{\sin\alpha_1}{\sin\alpha_2} < 1$$

$$\sin\alpha_1 < \sin\alpha_2$$

$$\alpha_1 < \alpha_2$$

Thus (b) is correct option.

44. Relation between critical angle of water (C_w) and that of the glass (C_g) is

(a) $C_w > C_g$ (b) $C_w < C_g$

(c) $C_w = C_g$ (d) $C_w = C_g = 0$

Ans : **Main 2003, 2000**

Given,

Critical angle of water $= C_w$

and Critical angle of glass $= C_g$

Refractive index of water,

$$\mu_w = \tfrac{4}{3}$$

and refractive index of glass,

$$\mu_g = 1.5$$

We also know that critical angle of water,

$$C_w = \sin^{-1}\left(\frac{1}{\mu_w}\right)$$

$$= \sin^{-1}\left(\frac{1}{\frac{4}{3}}\right)$$

$$= \sin^{-1}(0.75) = 48.6^\circ$$

Similarly, critical angle of glass,

$$C_g = \sin^{-1}\left(\frac{1}{\mu_g}\right)$$

$$= \sin^{-1}\left(\frac{1}{1.5}\right)$$

$$= \sin^{-1}(0.6667) = 42^\circ$$

Therefore, $C_w > C_g$.

Thus (a) is correct option.

45. If a ray of light in a denser medium strikes a rarer medium at an angle of incidence i, the angles of reflection and refraction are respectively r and r'. If the reflected and refracted rays are at 90° to each other, the critical angle for the given pair of media is

(a) $\sin^{-1}(\tan r)$ (b) $\sin^{-1}(\tan r')$

(c) $\cot^{-1}(\tan i)$ (d) $\tan^{-1}(\sin i)$

Ans : **SQP 2014**

Given,

Angle of incidence $= i$

Angle of reflection $= r$

Angle of refraction $= r'$

and angle between reflected and refracted rays, $= 90^\circ$

angle of reflection is equal to the angle of incidence i.e.,

$$i = r$$

We also know from Snell's law that the relation for refractive index of denser medium with respect to rarer medium μ is,

$$\frac{1}{\mu} = \frac{\sin i}{\sin r'} = \frac{\sin r}{\sin r'}$$

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39. A beam of light composed of red and green rays is incident obliquely at a point on the face of a rectangular glass slab. When coming out on the opposite parallel face, the red and green rays emerge from

(a) one point propagating in the same direction

(b) one point propagating in two different directions

(c) two points propagating in two different parallel directions

(d) two points propagating in two different non-parallel directions

Ans : **Main 2008, 2001**

when a beam of light is incident obliquely at a point on the face of a glass slab, it splits up into its constituents colours (or rays).

Therefore red and green rays emerge out form two points propagating in two different parallel directions, because both the rays have different angles of refraction inside the glass slab.

Thus (c) is correct option.

40. A ray of light strikes a glass plate at an angle θ. If angle between the reflected and refracted rays is a right angle, then refractive index of the glass plate is given by

(a) $\mu = \sin\theta$ (b) $\mu = \cos\theta$

(c) $\mu = \tan\theta$ (d) $\mu = \cot\theta$

Ans : **Comp 2009**

Given,

Angle of incidence, $i = \theta$

angle of reflection,

$$r' = \text{Angle of incidence } i = \theta$$

Since angle between reflected and refracted ray is 90°.

Therefore, $r' + r = 90^\circ$

$$\theta + r = 90^\circ$$

$$r = 90^\circ - \theta$$

We also know from the Snell's law that refractive index of glass plate,

$$\mu = \frac{\sin i}{\sin r}$$

$$= \frac{\sin\theta}{\sin(90^\circ - \theta)}$$

$$= \frac{\sin\theta}{\cos\theta} = \tan\theta$$

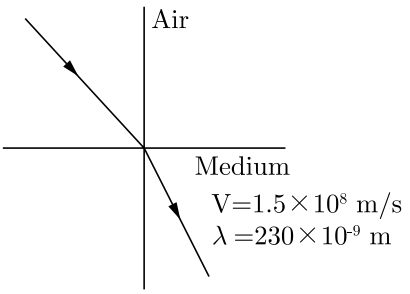
Thus (c) is correct option.

41. Abeam of light travels from air into a medium. Its speed and wavelength in the medium are 1.5×10^8 ms^{-1} and 230 nm respectively. The wavelength of light in air will be

(a) 230 nm (b) 345 nm

(c) 460 nm (d) 690 nm

Ans : **SQP 2023**



Now, $\mu = \frac{\alpha_2}{\alpha_1}$

here, $\mu_1 = 1$ (it is of medium air)

Now, $\mu = \mu_2 = \frac{\lambda_{air}}{\lambda_{medium}}$

Now, $\mu = \frac{c}{v} = \frac{3 \times 10^8}{1.5 \times 10^8} = 2$

$$\mu = \frac{\lambda_{air}}{\lambda_{medium}}$$

$$2 = \frac{\lambda_{air}}{230 \times 10^{-9}\text{m}}$$

$$\lambda_{air} = 460 \times 10^{-9}\text{m}$$

$$= 460 \text{ nm}$$

Thus (c) is correct option.

42. Critical angle for light moving from medium I to medium II is θ. The speed of light in medium I is v. Then speed in medium II is

(a) $v(1 - \cos\theta)$ (b) $\frac{v}{\sin\theta}$

(c) $\frac{v}{\cos\theta}$ (d) $v(1 - \sin\theta)$

Ans : **Comp 2018, 2015**

According to Snell's Law.

$$n_1 \sin i = n_2 \sin r \quad ...(1)$$

where, n_1 = Refractive index of first medium

n_2 = Refractive index of second medium

i = Angle of incidence

r = Angle of refraction

For critical angle,

Angle of incidence, $i = \theta$

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Ans : **Main 2023, 2014**

By using mirror formula,

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$\frac{1}{-20} = \frac{1}{v} + \frac{1}{-10}$$

$$\frac{1}{v} = \frac{1}{-20} + \frac{1}{10}$$

$$\frac{1}{v} = \frac{-1+2}{20} = \frac{1}{20}$$

$$v = 20\,\text{cm}$$

Virtual and 20 cm behind the mirror.

Thus (c) is correct option.

35. A fish which is at a depth of 12 cm in water ($\mu = 4/3$) is viewed by an observer on the bank of a lake. Its apparent depth as observed by the observer is

(a) 3 cm (b) 9 cm

(c) 12 cm (d) 16 cm

Ans : **Main 2015**

Refractive index

$$= \frac{\text{Real depth}}{\text{Apparent depth}}$$

Now, $\text{Apparent depth} = \dfrac{\text{Real depth}}{\text{Refractive index}}$

Here, real depth $= 12\,\text{cm}$,

refractive index $= 4/3$

$$\text{Apparent depth} = 12 \times \frac{3}{4} = 9\,\text{cm}$$

Thus (b) is correct option.

36. The angle of a prism is 60°. If green light of refractive index 1.5 passes through it, the angle of deviation will be

(a) 30° (b) 40°

(c) 50° (d) 60°

Ans : **SQP 2025**

Given,

Angle of prism, $A = 60^\circ$

and refractive index for green light,

$$\mu = 1.5$$

angle of deviation,

$$\delta = (\mu - 1)\,A$$

$$= (1.5 - 1) \times 60^\circ$$

$$= 0.5 \times 60^\circ = 30^\circ$$

Thus (a) is correct option.

37. The critical angle of light passing from glass to air is minimum for

(a) Red colour (b) Green colour

(c) Yellow colour (d) Violet colour

Ans : **SQP 2017, 2012**

The refractive index of glass,

$$\mu = \frac{c}{v} \qquad ...(1)$$

Here, $c =$ velocity of light

$v =$ velocity of light in medium

Since, $\mu = \dfrac{1}{\sin C}$ ...(2)

Here, $C =$ critical angle

From Eqn. (1) and (2), we get

$$\frac{c}{v} = \frac{1}{\sin C}$$

Hence, $v \propto \sin C$ [Since, $v = n\lambda$]

Thus critical angle is minimum for light with minimum v and that is violent.

Thus (d) is correct option.

38. The angle of minimum deviation for thin prism of refractive index (μ) is

(a) $(1-\mu)\,A$ (b) $(\mu-1)\,A$

(c) $(\mu+1)\,A$ (d) $(\mu+1)\,A^2$

Ans : **Main 2017**

Refractive index of the material of the prism,

$$\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\frac{A}{2}} \qquad ...(1)$$

If the prism angle is small than minimum.

Deviation (δ_m) is also small.

Hence, $\sin\left(\dfrac{A+\delta_m}{2}\right) = \dfrac{A+\delta_m}{2}$

and $\sin\dfrac{A}{2} = \dfrac{A}{2}$

From equation (1), we get

$$\mu = \frac{\frac{A+\delta_m}{2}}{\frac{A}{2}}$$

$$\mu = \frac{A+\delta_m}{A}$$

$$\mu A = A + \delta_m$$

$$\delta_m = \mu A - A$$

$$= A(\mu - 1)$$

Thus (b) is correct option.

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$$= \frac{\sin r}{\sin(90^\circ - r)} = \frac{\sin r}{\cos r}$$
$$= \tan r$$

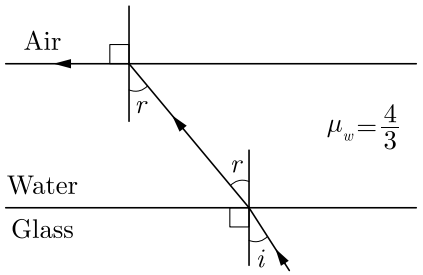
We also know that critical angle for the given pair of media,

$$C = \sin^{-1}\left(\frac{1}{\mu}\right)$$
$$= \sin^{-1}(\tan r)$$

where, $r' = 90^\circ - r$

Thus (a) is correct option.

46. A ray of light is incident at the glass-water interface at an angle i. If it finally emerges parallel to the surface of water as shown in the figure, the value of μ_g would be



(a) 1 (b) $\frac{4}{3}$

(c) $\frac{1}{\sin i}$ (d) $\frac{4\sin i}{3}$

Ans : **Main 2005**

Given,

Angle of incidence at glass-water interface $= i$

Angle of refraction at glass-water interface $= r$

Angle of refraction at water-air interface $= 90^\circ$

and refractive index of water,

$$\mu_w = \frac{4}{3}$$

We know from the Snell's law that for glass-water interface,

$$\frac{\alpha_w}{\alpha_g} = \frac{\sin i}{\sin r} \quad ...(1)$$

Similarly, for water-air interface,

$$\frac{1}{\mu_w} = \frac{\sin r}{\sin 90^\circ}$$
$$\frac{1}{\mu_w} = \sin r$$
$$\mu_w = \frac{1}{\sin r}$$

Substituting the value of μ_w in equation i,

$$\frac{1}{\sin r \times \mu_g} = \frac{\sin i}{\sin r}$$

Refractive index of glass,

$$\mu_g = \frac{1}{\sin i}$$

Thus (c) is correct option.

47. Which should be the maximum acceptance angle at the air-core interface of an optical fibre, if μ_1 and μ_2 are the refractive indices of the core and the cladding respectively ?

(a) $\sin^{-1}\left(\frac{\alpha_2}{\alpha_1}\right)$ (b) $\tan^{-1}\left(\frac{\alpha_1}{\alpha_2}\right)$

(c) $\tan^{-1}\left(\frac{\alpha_2}{\alpha_1}\right)$ (d) $\sin^{-1}(\sqrt{\alpha_1^2 - \alpha_2^2})$

Ans : **Main 2013**

Given,

Refractive index of core $= \mu_1$

and, refractive index of cladding, $= \mu_2$

critical angle for the optical fibre,

$$C = \sin^{-1}\left(\frac{\alpha_2}{\alpha_1}\right)$$
$$\sin C = \frac{\alpha_2}{\alpha_1}$$

And for maximum acceptance angle (θ_{max}) at air-core interface, the incidence angle at core-cladding interface is equal to the critical angle for the optical fibre (i.e., $i = C$)

Therefore maximum value of refracted angle at air-core interface,

$$r_{max} = 90^\circ - i$$
$$= 90^\circ - C$$

We also know according to Snell's law that at air-core interface,

$$\mu_a \sin(\theta_{max}) = \mu_1 \sin(r_{max})$$
$$\sin(\theta_{max}) = \mu_1 \sin(90^\circ - C)$$
$$= \mu_1 \cos C$$
$$\sin(\theta_{max}) = \mu_1\sqrt{1 - \sin^2 C}$$
$$= \alpha_1\sqrt{1 - \left(\frac{\alpha_2}{\alpha_1}\right)^2}$$
$$= \sqrt{\alpha_1^2 - \alpha_2^2}$$
$$\theta_{max} = \sin^{-1}(\sqrt{\alpha_1^2 - \alpha_2^2})$$

where, μ_a = refractive index of air equal to 1

Thus (d) is correct option.

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Ans : **Main 2003**

In vacuum all the colours have same velocity but their velocity changes when they enter in a medium. In the medium their velocity changes due to change in their wavelength.

$$v = n\lambda$$

If λ changes, v also changes for a particular colour therefore, different colours have different wavelength (λ).

Thus (d) is correct option.

58. **Assertion :** The image of a virtual object due to a plane mirror is real.

Reason : If the rays seem to be converging at a point behind a plane mirror, they are reflected and they actually meet in front of the mirror.

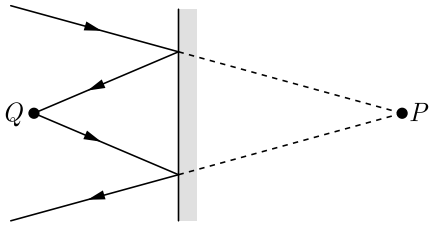
(a) Both Assertion and Reason are correct and Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not the a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Main 2018**



The image of a real object is virtual while that of a virtual object (as shown) is real.

Thus (a) is correct option.

59. **Assertion :** Position of image approaches focus of a lens, only when object approaches infinity.

Reason : Par-axial rays incident parallel to principal axis intersect at the focus after refraction from lens.

(a) Both Assertion and Reason are correct and Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not the a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Main 2009**

When an object is at a very large distance, the rays coming from it become nearly parallel to the principal axis. A lens refracts parallel paraxial rays so that they meet at the principal focus. Therefore, the image approaches the focus only when the object approaches infinity. Hence, both statements are correct.

Thus (a) is correct option.

60. **Assertion :** Plane mirror may form real image.

Reason : Plane mirror forms virtual image, if object is real.

(a) Both Assertion and Reason are correct and Reason is a correct explanation of the Assertion.

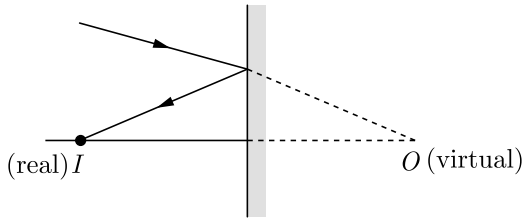
(b) Both Assertion and Reason are correct but Reason is not the a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Main 2010**

Plane mirror may form real image, if object is virtual.



Thus (b) is correct option.

61. **Assertion :** There exists two angles of incidence for the same magnitude of deviation (except minimum deviation) by a prism kept in air.

Reason : In a prism kept in air, a ray is incident on first surface and emerges out of second surface. Now if another ray is incident on second surface (of prism) along the previous emergent ray, then this ray emerges out of first surface along the previous incident ray. This particle is called principle of reversibility of light.

(a) Both Assertion and Reason are correct and Reason is a correct explanation of the Assertion.

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(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Main 2009**

Air bubble shines in water due to total internal reflection from the surface of the bubble.

So, Assertion is correct and Reason is incorrect.

Thus (c) is correct option.

53. **Assertion :** Diamond glitters brilliantly.

Reason : Diamond does not absorb sunlight.

(a) Both Assertion and Reason are correct and Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not the a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Main 2017**

Diamond glitters brilliantly because of high refractive index and less critical angle.

Thus (b) is correct option.

54. **Assertion :** The stars twinkle while the planets do not.

Reason : the stars are much bigger in size than the planets.

(a) Both Assertion and Reason are correct and Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not the a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **SQP 2002**

Stars twinkle because of changing refractive index of atmosphere. As the apparent size of stars are small, the effect of this change on the direction of rays coming from star is more pronounced.

Thus (b) is correct option.

55. **Assertion :** A red object appears dark in the yellow light.

Reason : The red colour is scattered less.

(a) Both Assertion and Reason are correct and Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not the a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Main 2006, 2003**

A red object appears dark in the yellow light because red object absorbs all the light falling on it except red. The Reason which is a fact can not be assigned to the Assertion.

Thus (b) is correct option.

56. **Assertion :** By roughening the surface of a glass sheet its transparency can be reduced.

Reason : Glass sheet with rough surface absorbs more light.

(a) Both Assertion and Reason are correct and Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not the a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Main 2025, 2018**

The transparency of rough glass is reduced due to scattering of light.

Thus (c) is correct option.

57. **Assertion :** Different colours travel with different speed in vacuum.

Reason : Wavelength of light depends on refractive index of medium.

(a) Both Assertion and Reason are correct and Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not the a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) The Assertion is incorrect but the Reason is correct.

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Large diameter core, angle B is smaller. In the former case $\angle A$ is large so the possibility of this angle becoming greater than critical angle is more. Hence, the change of internal reflection is more.

Thus (a) is correct option.

65. **Assertion :** The refractive index of diamond is $\sqrt{6}$ and that of liquid is $\sqrt{3}$. If the light travels from diamond to the liquid, it will totally reflected when the angle of incidence is 30°.

Reason : $\mu = \frac{1}{\sin C}$, where μ is the refractive index of diamond with respect to liquid.

(a) Both Assertion and Reason are correct and Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not the a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) The Assertion is incorrect but the Reason is correct.

Ans : SQP 2024

$$^{a}\mu_{d} = \sqrt{6}$$

$$^{a}\mu_{\ell} = \sqrt{3}$$

$$^{\ell}\mu_{d} = ?$$

$$^{a}\alpha_{d} \times {}^{d}\alpha_{\ell} \times {}^{\ell}\alpha_{a} = 1$$

$$\sqrt{6} \times {}^{d}\mu_{\ell} \times \frac{1}{\sqrt{3}} = 1$$

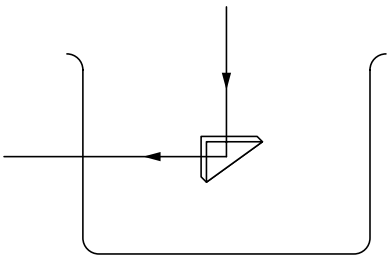
$$^{d}\mu_{\ell} = \frac{\sqrt{3}}{\sqrt{6}} = \frac{1}{\sqrt{2}}$$

$$^{\ell}\mu_{d} = \sqrt{2}$$

If C be the critical angle, then $C = 45^\circ$. As angle of incidence $< 45^\circ$, it will not be internally reflected. So Assertion is incorrect Reason is correct.

Thus (d) is correct option.

66. **Assertion :** The maximum refractive index of liquid for total internal reflection of the ray passing through the prism as shown in figure must be $\sqrt{2}$.



Reason : Here, critical angle is 45°.

(a) Both Assertion and Reason are correct and Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not the a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : Main 2011

In case of total internal reflection, the minimum refractive index is given by the relation.

$$\mu = \frac{1}{\sin c} = \frac{1}{\sin 45^\circ}$$

$$= \frac{1}{1/\sqrt{2}} = \sqrt{2}$$

Thus (a) is correct option.

67. **Assertion :** A double convex lens ($\mu = 1.5$) has focal length 10 cm. When the lens is immersed in water ($\mu = 4/3$) its focal length becomes 40 cm.

Reason : $\frac{1}{f} = \frac{\alpha_1 - \alpha_m}{\alpha_m} = \left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

(a) Both Assertion and Reason are correct and Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not the a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : Main 2007, 2004

Using the given relation,

$$\frac{1}{10} = \left(\frac{1.5-1}{1}\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\frac{1}{10} = 0.5\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad \ldots(1)$$

In the second case,

$$\mu = \frac{4}{3}$$

$$\frac{1}{f} = \left(\frac{1.5 - \frac{4}{3}}{4/3}\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad \ldots(2)$$

Dividing (2) from (1),

$$\frac{f}{10} = \frac{0.5}{0.5/4} = \frac{4 \times 0.5}{0.5}$$

$$f = 4 \times 10 = 40 \text{ cm}$$

Thus (a) is correct option.

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(b) Both Assertion and Reason are correct but Reason is not the a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Main 2006**

For a prism, except at minimum deviation, two different angles of incidence can produce the same angle of deviation. This happens because of the principle of reversibility of light, according to which the path of a light ray remains the same when its direction is reversed.

Thus (a) is correct option.

62. **Assertion :** The formula connecting u, ν and f for a spherical mirror is valid only for mirrors whose sizes are very small compared to their radii of curvature.

Reason : Laws of reflection are strictly valid for plane surfaces, but not for large spherical surface.

(a) Both Assertion and Reason are correct and Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not the a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Main 2014**

The mirror formula is valid only for small aperture spherical mirrors because it is based on paraxial rays and approximation methods. However, the laws of reflection are valid for all reflecting surfaces, including large spherical surfaces. Therefore, the Reason is incorrect.Thus (c) is correct option.

63. **Assertion :** A concave mirror and convex lens both have the same focal length in air. When they are submerged in water, they will have same focal length.

Reason : The refractive index of water is smaller than the refractive index of air.

(a) Both Assertion and Reason are correct and Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not the a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **SQP 2017**

If a mirror is placed in a medium other than air, its focal length does not change as $f = R/2$. But for the lens,

$$\frac{1}{f_g} = ({}_a n_g - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

and

$$\frac{1}{f_w} = ({}_w n_g - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

As ${}_w n_g < {}_a n_g$, hence focal length of lens in water increase.

The refractive index of water is 4/3 and that of air is 1. Hence, refractive index of water is greater than that of air.

Thus (d) is correct option.

64. **Assertion :** In optical fibre, the diameter of the core is kept small.

Reason : This smaller diameter of the core ensures that the fibre should have incident angle more than the critical angle required for total internal reflection.

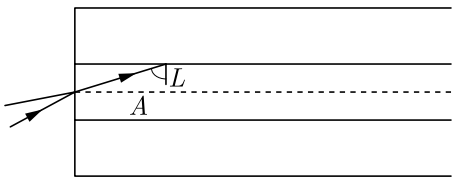
(a) Both Assertion and Reason are correct and Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not the a correct explanation of the Assertion.

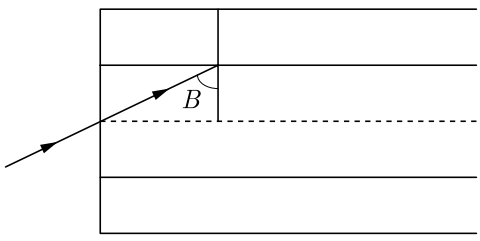
(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **SQP 2019**



Small diameter core, angle A is larger



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ASSERTION AND REASON

DIRECTION : These questions contains of two statements, each printed as Assertion and Reason. While answering these questions, you are required to choose any one of the following five responses.

48. **Assertion :** The colour of the green flower seen through red glass appears to be dark.

Reason : Red glass transmits only red light.

(a) Both Assertion and Reason are correct and Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not the a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **SQP 2014**

A green flower absorbs all the light except green coloured light. So when red glass transmits only red light and falls on green flower, it absorbs all the light. Therefore, colour of the green flower becomes dark.

Thus (a) is correct option.

49. **Assertion :** Corpuscular theory fails in explaining the velocities of light in air and water.

Reason : According to corpuscular theory, light should travel faster in denser medium than in rarer medium.

(a) Both Assertion and Reason are correct and Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not the a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Main 2017**

Corpuscular theory fails to explain the velocity of light in air and water because it predicted light to have more velocity in denser medium where as the fact is just the opposite.

Thus (a) is correct option.

NODIA

50. **Assertion :** The setting sum appears to be red.

Reason : Scattering of light is directly proportional to the wavelength.

(a) Both Assertion and Reason are correct and Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not the a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Main 2010**

Setting sun appears to be red because red light which has greatest wavelength is least scattered and reaches our eyes the most. Other wavelength are scattered to the longest extent. So, reason given is wrong.

Thus (c) is correct option.

51. **Assertion :** Blue colour of sky appears due to scattering of blue colour.

Reason : Blue colour has shortest wave length in visible spectrum.

(a) Both Assertion and Reason are correct and Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not the a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **SQP 2016**

Blue colour of sky is due to scattering of blue colour to the maximum extent by dust particles. Blue colour appears to be coming from the sky. Blue colour has the least wavelength.

Thus (a) is correct option.

52. **Assertion :** The air bubble shines in water.

Reason : Air bubble in water shines due to refraction of light.

(a) Both Assertion and Reason are correct and Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not the a correct explanation of the Assertion.

ONE MARK QUESTIONS

68. Name the physical principle on the basis of which optical fibres work.

Ans : **Main 2020, 2016, 2014**

Total internal reflection.

69. Name the physical principle on which the working of optical fibre is based.

Ans : **Main 2016, 2014**

Optical fibre works on the principle of total internal reflection.

70. What is meant by a microscope in normal use?

Ans : **Main 2023**

A microscope is a device that allows you to see items that are too small for the naked eye to see.

71. State one assumption made in deriving the formula $\frac{n_2}{v} = -\frac{n_1}{u} = \frac{n_2 - n_1}{R}$ for refraction at a spherical interface.

Ans : **Main 2003**

The assumption is that we concerned the rays to be paraxial (rays close to principal axis) only.

72. Name an optical device, which when used with a spectrometer, can determine the wavelength of the given monochromatic light.

Ans : **Main 2010**

Prism and telescope.

73. Name any two phenomena which take place in the formation of a rainbow.

Ans : **Main 2023**

The formation of a rainbow involves all three phenomena : Refraction, Dispersion and total internal reflection.

74. Define critical angle for a given medium.

Ans : **Main 2025**

The critical angle for two given media is the angle of incidence in the denser medium for which the angle of refraction in the rarer medium is 90°.

75. In an achromatic combination of two lenses, why should we have the materials of the lenses different?

Ans : **Main 2002**

The different lenses have different dispersive power, so in an achromatic combination of lenses we use lenses of different materials to minimise chromatic aberration

76. What is the main reason for axial chromatic aberration in the formation of images by a lens?

Ans : **Main 2008**

Focal length of a lens is different for different colours due to variation of refractive index with wavelength of light, so images of different colours are formed at different positions along the axis of the lens.

77. Where should an object be kept infront of a convex lens in order to get an image of the same size as the object?

Ans : **Main 2022 Sem-II**

To get an image of the same size as the object in a convex lens, the object should be placed at a distance of twice the focal length or at the centre of curvature of the lens.

78. Define the angular magnification of an optical instrument.

Ans : **Main 2004**

Angular magnification of an optical instrument is defined as the ratio of the visual angle subtended by the image formed by the instrument at the eye to the visual angle subtended by the object at an unaided eye. i.e. $M = \frac{\beta}{\alpha}$

79. What conditions must be satisfied by two thin lenses kept in contact, so that they form an achromatic doublet, i.e. a combination free from chromatic aberration?

Ans : **Main 2012**

The conditions are as follows :

(i) Both the lenses, one must be converging and other must be diverging in nature.

(ii) Both the lenses should be of different materials.

80. Write down the lens maker's formula using standard symbols.

Ans : **Main 2002**

Lens maker's formula is

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

where, f is focal length of lens

μ is refractive index of material of lens

R_1 is radius of curvature of first surface.

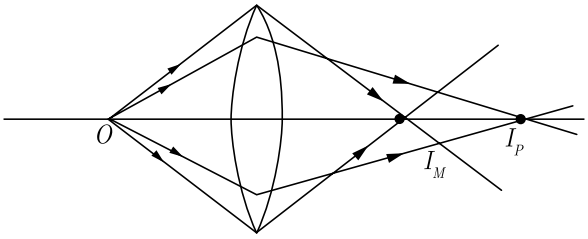
R_2 is radius of curvature of second surface.

NODIA

96. How can the spherical aberration produced by a lens be minimised?

Ans : **Main 2017**

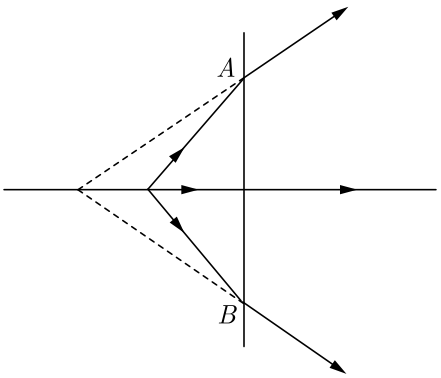
The inability of a spherical mirror or a lens of large aperture to bring the marginal as will as paraxial rays of a wide beam of right to focus at a single point is called spherical aberration.



Spherical aberration

97. The line AB in the ray diagram represents a lens. State whether the lens is convex or concave.

Ans : **Comp 2015**



Ans :

It is a convex or converging lens.

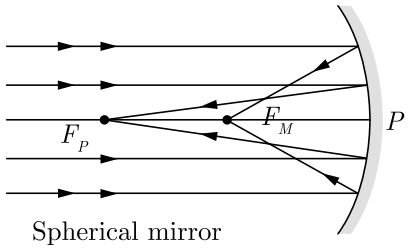
Reason The refracted ray is bending towards the principal axis.

98. Draw a diagram to illustrate spherical aberration of a convex lens.

Ans : **Main 2001**

Spherical aberration in the lens is the defect in the quality of the image because of which, the paraxial and marginal rays are focussed at different points on the principal axis of the lens. This arises due to different focal lengths (or different curvature) of the lens.

The following figure illustrates it.

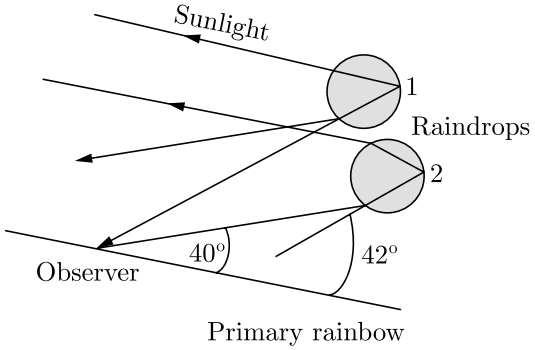


Spherical mirror

99. Draw a neat and labelled ray diagram to show the formation of primary rainbow.

Ans : **SQP 2023**

The primary rainbow is a result of three step process. It is formed by the rays which undergo one internal reflection (total internal reflection) and two reflections before emerging finally from the water droplets. In primary rainbow, red colour is on the top and violet on the bottom.

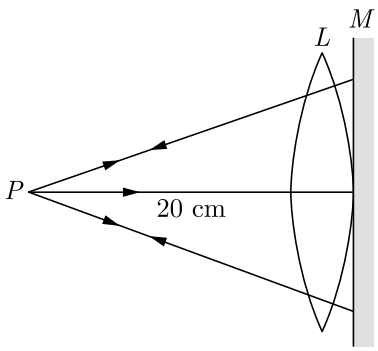


Primary rainbow

100. A convex lens is placed in contact with a plane mirror. A point object at a distance of 20 cm on the axis of is combination has its image coinciding with itself. That is the length of the lens?

Ans : **SQP 2014**

The figure shows a convex lens L in contact with a plane mirror M. P is the point object kept in front of this combination at a distance of 20 cm from it.



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light by water droplet whereas secondary rainbow is formed because of two total internal reflections and two refraction of white light by water droplet.

90. State any two differences between primary rainbow and secondary rainbow.

Ans : **Main 2018**

A rainbow is formed due to the refraction followed by dispersion of white light ray by a water droplet in the atmosphere.

Primary rainbow is formed because of one total internal reflection and two refraction of white light by water droplet whereas secondary rainbow is formed because of two total internal reflections and two refraction of white light by water droplet.

A secondary rainbow is more brighter than primary rainbow.

91. What is meant by dispersive power? Write an expression of dispersive power in terms of refractive indices.

Ans : **SQP 2018, 2015**

Dispersive power is the ability of the prism material to cause dispersion. It is defined as the ratio of angular dispersion to the mean deviation when a white light of beam is passed through prism.

So, dispersive power $(\omega) = \frac{\alpha_V - \alpha_R}{(\alpha - 1)}$

where, μ_V = refractive index for violet colour

μ_R = refractive index for red colour.

92. For the same value of angle of incidence, the angles of refraction in three media A, B and C are 15°, 25° and 35° respectively. In which medium, would the velocity of light be minimum?

Ans : **Main 2025**

From Snell's law,

$$\mu = \frac{\sin i}{\sin r} = \frac{c}{v}$$

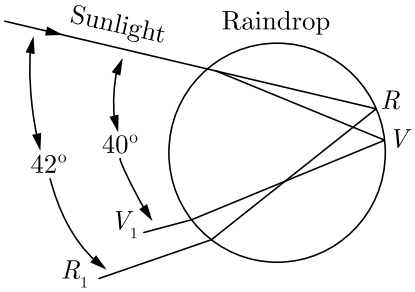
$v\sqrt{\propto \sin r}$ for given value of i

Smaller angle of refraction, smaller the velocity of light in medium.

Velocity of light is minimum in medium A as angle of refraction is minimum, *i.e.*, 15°.

93. Draw ray diagram to illustrate the formation of primary rainbow by refraction and total internal reflection of sunlight in water drops.

Ans : **Main 2005, 2003**



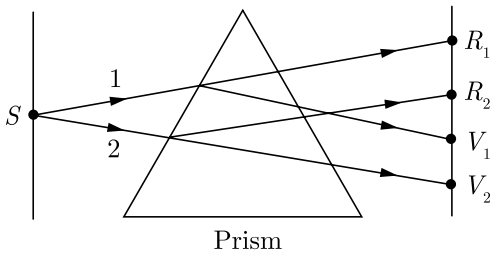
Disersion of sunlight of single rainbow

NODIA

94. Draw a labelled ray diagram for the production of pure spectrum.

Ans : **Main 2002**

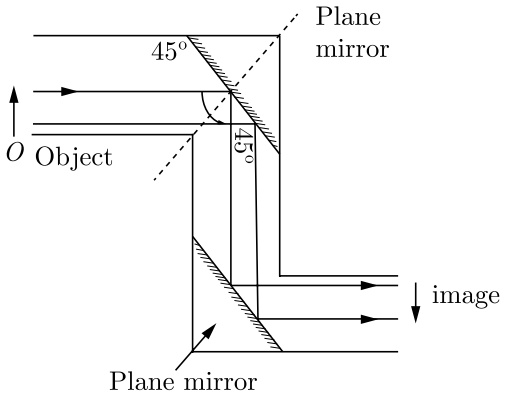
When a beam of white light coming from a slit and passes through a prism, it splits up into its constituent colours and form a colour band from red to violet on the screen. This colour band is called spectrum.



95. Draw a diagram to show how an image is produced by a pair of two reflecting plane mirrors arranged as in a periscope.

Ans : **Main 2001**

The ray diagram of the periscope is shown as below (It uses right angled isosceles prism).



128. How does focal length of a lens change when red light incident on it is replaced by violet light? Give reason for your answer.

Ans : **Main 2010**

The refractive index of the material of a lens increased with the decrease in wavelength of the incident light. So, focal length will decrease with decrease in wavelength according to the formula.

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Thus, when we replace red light with violet light then due to increase in wavelength the focal length of the lens will decrease.

129. State three conditions for formation of pure spectrum.

Ans : **Main 2007**

Three conditions for the formation of pure spectrum are

(a) The slit should be narrow.

(b) The rays falling on the prism should be parallel.

(c) The prism should be placed in minimum deviation position.

130. Write any one use for each of the following mirrors.

(i) Convex

(ii) Concave

Ans : **Main 2019**

(i) A convex mirror is used as a reflector in street lamps.

(ii) Concave mirrors are used by ENT doctors to examine ear, nose and throat.

131. When does Snell's law fail in refraction?

Ans : **SQP 2016, 2012**

Snell's law fails, if a ray of light in a denser medium incident on a rarer medium at an angle more than the critical angle for that pair of media, then the ray of light is totally reflected back into the denser medium instead of going to the rarer medium as predicted by Snell's law. Hence in this situation, Snell's law fails in refraction.

132. Define critical angle and write its conditions.

Ans : **SQP 2020**

Critical angle for a pair of given media in contact can be defined as, "the angle of incidence in denser medium for which angle of refraction in rarer medium is 90°". The value of critical angle depends on the nature of two media in contact.

Condition for Critical Angle :

1. Ray of light should be goes from denser of rarer medium.
2. Refraction angle is always 90°.

133. The refractive index of diamond is much greater than that of glass. How does a diamond cutter make use of that fact?

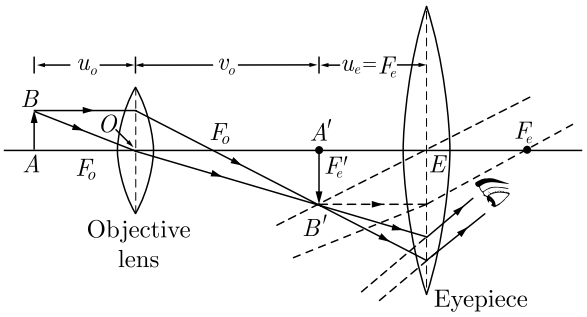
Ans : **Main 2017**

The refractive index of diamond is much higher than that of glass. Due to high refractive index, the critical angle for diamond air interface is low. The diamond is cut suitably so that the light entering the diamond from any face suffers multiple total internal reflections at the various surfaces.

134. Draw a schematic ray diagram of a compound microscope with the final image formed at infinity.

Ans : **Main 2000**

The diagram of a compound microscope, when the final image is formed at infinity is shown below.



135. What is total internal reflection? What are the conditions for it?

Ans : **Main 2024**

The phenomenon in which a ray of light travelling at an angle of incidence greater than the critical angle from denser to rarer medium is totally reflected back into the denser medium is called total internal reflection.

Necessary Conditions for Total Internal Reflection:

1. Light must travel from an optically denser to an optically rarer medium.
2. The angle of incidence in the denser medium must be greater than the critical angle for the two media.

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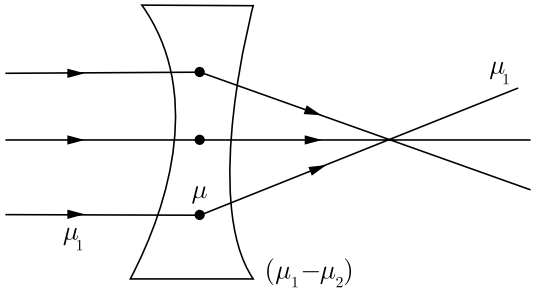
Since, the image is coinciding with the object itself, the always from the object after refraction from the lens fall on the mirror M and from an image coinciding with the object itself.

The image is formed at the focus of the lens, So, focal length of the lens is 20 cm.

101. Refractive index of the material of a concave lens is μ. The lens is immersed in a medium of refractive index μ_1 $(\mu_1 > \mu)$. A parallel beam of light is incident on the lens. Draw a diagram to show the path of emergent rays.

Ans : **Main 2005, 2001**

The behaviour is reversed in accordance with Lens Maker's formula.



$$\frac{1}{f} = \left(\frac{\alpha_2}{\alpha_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

where, symbols have their usual meaning.

$$\frac{1}{f} = \left(\frac{\alpha}{\alpha_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = +\text{ ve}$$

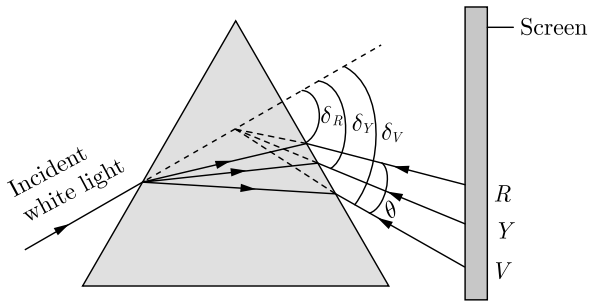
f = focal length is positive hence, it will behave as convex lens.

102. Define angular dispersion.

Ans : **Main 2022 Sem-II**

The angular dispersion produced by a prism for white light is the difference in the angle of deviation for two extreme colours, violet and red.

According to given figure, angular dispersion



$$\theta = \delta_V - \delta_r$$
$$= (u_V - u_r)\, A$$

where,

δ_u = deviation angle of violet light,

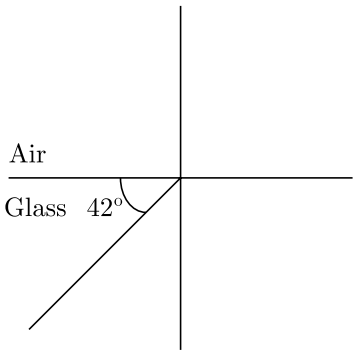
δ_r = deviation angle of red light,

u_V = refractive index for violet light,

u_r = refractive index for red light,

A = angle of prism.

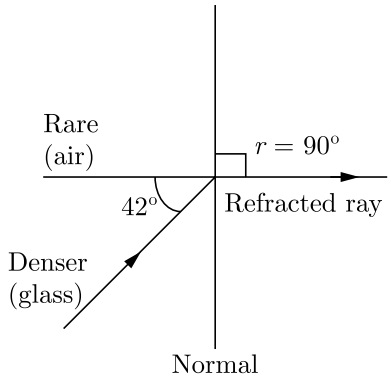
103. Complete the ray diagram shown in figure, given that the critical angle for air-glass pair is $i_c = 42^\circ$.



Ans : **SQP 2018**

When incident angle is greater than or equal to the critical angle, only then total internal reflection takes place.

Here, $\angle i = \angle C$, $\angle r = 90^\circ$



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81. Why does the Sun look reddish at sunset or sunrise?

Ans : **Main 2013**

During sunset or sunrise, the sun is just above the horizon, the blue colour gets scattered most by the atmospheric molecules while red light gets scattered least, hence sun appears red.

Reason : Scattering intensity $I \propto \frac{1}{\lambda^4}$ and $\lambda_B << \lambda_R$.

82. A simple microscope or a magnifying glass with a focal length 5 cm forms an image at the near point of the eye. Find its magnification.

Ans : **Main 2006, 2002**

For a simple microscope, we know that for near point, magnifying power,

$$M = 1 + \frac{D}{f} = 1 + \frac{25}{5} = 6$$

D= least distance of distinct vision and

f = focal length of lens

83. State two basic differences between primary and secondary rainbows.

Ans : **Main 2006**

Differences between Primary and Secondary Rainbows are as follows :

Primary Rainbow	**Secondary Rainbow**
Light rays suffer single total internal reflection.	Light rays suffer two total internal reflections.
Outer edge is red and inner edge is violet.	Outer edge is violet and inner edge is red.

84. For the same angle of incidence, the angle of refraction in two media A and B are 25° and 35° respectively. In which one the two media is the speed of light lesser?

Ans : **SQP 2024**

Medium, $A; \mu = \frac{\sin i}{\sin r}$

$$= \frac{\text{Speed of light on air}}{\text{Speed of light in medium}}$$

μ is higher therefore speed is lesser.

85. What is chromatic aberration? How can it be minimised or eliminated?

Ans : **Main 2015**

Chromatic Aberration is a type of distortion in which there is a failure of lens of focus all colours to the same convergence point.

It can be minimise or eliminated by following

(a) By providing stoppers.

(b) By multiple refraction and reflection.

86. For an achromatic combination of lenses in contact, why should the lens be of opposite nature?

Ans : **Main 2005**

The condition for the achromatic combination of the lenses in contact is as below:

$$\frac{\omega_1}{f_1} + \frac{\omega_2}{f_2} = 0 \Rightarrow \frac{\omega_1}{f_1} = -\frac{\omega_2}{f_2}$$

$$\frac{\omega_1}{\omega_2} = \frac{-f_1}{f_2}$$

where, ω_1 and ω_2 are dispersive powers of the material of the lens, which are always positive. Thus, one of the lens must have focal length of opposite sign.

87. Define dispersive power (for light) of a medium.

Ans : **Main 2003**

Dispersive power of a prism is defined as the ratio of angular dispersion to the mean deviation produced by the prism. It is represented by ω.

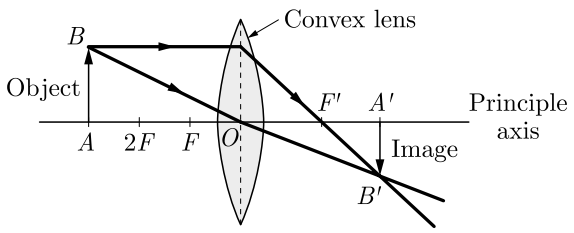
$$\text{Dispersive power, } \omega = \frac{\text{Angular dispersion}}{\text{Mean deviation}}$$

$$= \frac{\delta_V - \delta_R}{\delta} = \frac{(u_V - u_R)\,A}{(u-1)\,A}$$

$$\omega = \frac{u_V - u_R}{(u-1)}$$

88. A point object is placed above principal axis at a distance three times focal length of a convex lens. Draw ray diagram showing position of image.

Ans : **Comp 2020**



89. State any one difference between a primary rainbow and a secondary rainbow.

Ans : **Main 2015, 2010**

A rainbow is formed due to the refraction followed by dispersion of white light ray by a water droplet in the atmosphere.

Primary rainbow is formed because of one total internal reflection and two refraction of white

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117. Under what condition does a biconvex lens of glass having a certain refractive index act as a plane glass sheet when immersed in a liquid?

Ans : **SQP 2012**

A biconvex lens will act like a plane sheet of glass if than is immersed in a liquid the same index of refraction as itself, In this case, the focal length $\frac{1}{f} = 0$ or $f \to \infty$.

118. Does the critical angle depend on the wavelength of light?

Ans : **Main 2013**

Yes, Since critical angle depends upon the refractive index of the medium and refractive index of the medium depends upon the wavelength of light. So critical angel also depends upon the wavelength of light.

119. How does the angle of minimum depiction of a glass prism very, if the incident violet light is replaced by red light? Give reason.

Ans : **SQP 2010**

$$\mu = \sin \frac{\left(\frac{\delta_m + A}{2}\right)}{\sin \frac{A}{2}}$$

For red light $\mu =$ least, $\delta_m \to$ will reduce

120. Under what condition does a biconvex lens of glass having a certain refractive index act as a plane glass sheet when immersed in a liquid?

Ans : **Main 2019**

When, $\mu_l = \mu_g$

where $\mu_l =$ Refractive index of liquid

and $\mu_g =$ Refractive index of glass.

121. A concave lens of refractive index 1.5 is immersed in a medium of refractive index 1.65 what is the nature of the lens?

Ans : **Main 2016**

In the given case, concave lens is immersed in medium having refractive index greater than the refractive index of the material of the lens ($1.65 > 1.5$). Therefore, it will behave as a converging lens.

122. What are the assumptions followed to study refraction from spherical surfaces?

Ans : **SQP 2019, 2014**

1. The object is taken a point object on the principle axis.
2. The aperture of the spherical refracting surface is small.
3. Incident and refracted rays make small angels with principal axis.

123. Define absolute refractive index of a medium.

Ans : **Comp 2019, 2016**

The absolute refractive index of a medium (μ) is defined as the ratio of velocity of light in vacuum (c) to the velocity of light in the medium (v)

i.e., $\mu = \frac{c}{v}$

As, $c > v$ (Hence $\mu > 1$)

124. Define the magnifying power of a microscope in terms of visual angles.

Ans : **Main 2004**

Magnifying power of a microscope is defined as the ratio of visual angle subtended by the image at the eye to the visual angle subtended by the object at the eye when placed at least distance of distinct vision.

i.e., $m = \frac{\beta}{\alpha}$

125. What are the advantages of total reflecting prism over a plane mirror?

Ans : **Main 2017**

1. It reflects whole light i.e. its reflection is 100%.
2. No silvering is required for reflection of light through total reflecting prisms.
3. In reflecting prism, multiple reflection does not take place and the single image formed is bright.

126. What is the cause of dispersion of light?

Ans : **Comp 2025**

The refractive index of a material depends upon the wavelength as the velocity of light in a material depends upon wavelength, since white light is composed of different colours, so different colours are deviated through different angles and we get dispersion of light.

127. A biconvex lens made of a transparent material of refractive index 1.5 is immersed in a water of refractive index 1.33. Will the lens behave as a converging or a converging lens? Give reason.

Ans : **Main 2016**

A biconvex lens acts as a converging lens in air because the refractive index of air is less than that of the material of the lens. The refractive index of water is less than the refractive index of the material of the lens (1.5). So, its nature will not change, it behaves as a converging lens.

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TWO MARKS QUESTIONS

104. State any one advantage of using a reflecting telescope in place of a refracting telescope.

Ans : Main 2015, 22 Sem-II

Reflecting telescope removes chromatic and spherical aberration, high resolving power.

105. Why all over the world, giant telescopes are of reflecting type? State any one reason.

Ans : Main 2009, 2007

It has a large aperture due to which it gathers more light and brighter image is obtained.

106. State any method of increasing the resolving power of an astronomical telescope.

Ans : SQP 2013

to increase the resolving power of an astronomical telescope, we need to increase the numerical aperture of the objective.

107. State how the resolving power of an astronomical telescope can be increased.

Ans : Main 2010

By increasing the diameter of objective lens, or by decreasing wavelength of light, we can increase the resolving power of a telescope, because $R = D/1.22\lambda$.

108. Define resolving power of a simple astronomical telescope.

Ans : Main 2025

Resolving Power: The ability of the telescope to produce distinctly separate images of two close objects is called resolving power of the telescope.

109. Write the relationship between angle of incidence i, angle of prism A and angle of minimum deviation for triangular prism.

Ans : SQP 2017

$$i = \frac{A + \delta_m}{2}$$

Where $\delta_m =$ angle of minimum deviation.

110. State one advantage of a reflecting telescope over refracting telescope.

Ans : SQP 2015

One advantage of a reflecting telescope over refracting telescope is that the image formed by reflecting telescope is larger and brighter than the image formed by a refracting telescope.

111. Explain the statement: "Angular magnification of a compound microscope in normal use is 30".

Ans : Main 2010

The statement can be explained as the visual angle subtended on eye with telescope is 30 times more than the angle without telescope, when the object is at the least distance of distinct vision.

112. What is the advantage of a compound microscope over a simple microscope?

Ans : Main 2016, 2010

In a simple microscope, there is only one lens, whereas in a compound microscope there are two lenses. Therefore, the magnifying power of a compound microscope is more than that of a simple microscope.

113. State the criteria for the phenomenon of total internal reflection of light to take place.

Ans : Comp 2020

Following are the criteria for total internal reflection

(i) Light must pass from a denser to a rarer medium.

(ii) Angle of incidence must be greater than critical angle.

114. A lens behaves as a converging lens in air and a diverging lens in water $\left(\mu = \frac{4}{3}\right)$. What will be the condition on the value of refractive index (μ) of the material of the lens?

Ans : SQP 2015

Refractive index of the material of lens is less than the refractive index of water.

115. When monochromatic light travels from one medium to another, its wavelength changes but frequency remains the same. Explain

Ans : Main 2024

Because refractive index for a given pair of media depends on the ratio of wavelengths and velocity of light in two medium and not on a frequency.

116. When light travels from an optically denser medium to a rarer medium, why does the critical angle of incidence depend on the colour of light?

Ans : Comp 2018

The refractive index is different for different colour wavelength as $\mu = a + \frac{b}{\lambda^2}$. Hence, critical angle $\sin i_C = \frac{1}{\mu}$ would also be different colour of light.

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136. A convex lens of focal length f_1 is kept in contact with a concave lens of focal length f_2. Find the focal length of the combination.

Ans : **SQP 2013, 2010**

For convex lens,

Focal length, $f = f_1$

and for concaver lens,

Focal length, $f = -f_2$

The equivalent focal length of the combination of lenses

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{-f_2}$$

$$F = \frac{f_1 f_2}{f_2 - f_1}$$

137. What is the difference between Magnification and Magnifying power?

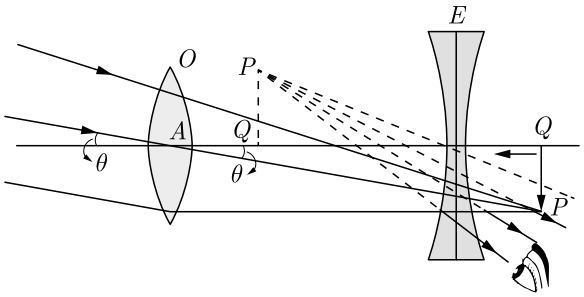
Ans : **SQP 2019**

The difference between Magnification and Magnifying power are as follows :

	Magnification	**Magnifying Power**
1.	Magnification is the ratio of image size to object size.	Magnifying power is the ratio of visual angle subtended by the image (β) and visual angle subtended by the object (α).
2.	The range of magnification is ∞ to $+\infty$	The value of magnifying power lies between $\frac{D}{f}$ and $\left(1+\frac{D}{f}\right)$

138. Draw a labelled diagram of a telescope which gives erect images of distant objects.

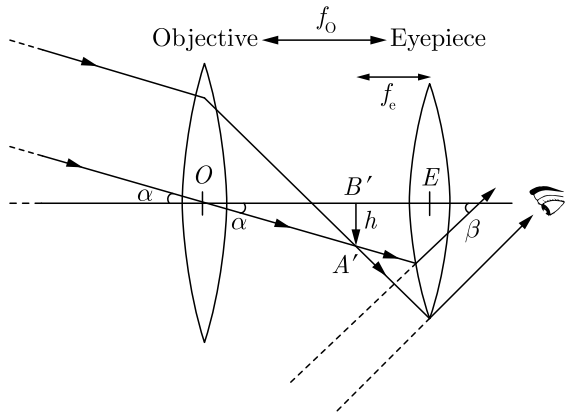
Ans : **SQP 2015**



We use a Galileo telescope to get an erect image of objects. The objective is a convex lens while the eye - piece is a concave.

139. Draw ray diagram to illustrate the formation of image at infinity in a refracting telescope.

Ans : **Main 2003**



140. With regard to an astronomical telescope of refraction type, state how you will increase its

(i) magnifying power

(ii) resolving power

Ans : **Main 2015**

(i) Magnifying power can be increased by increasing focal length of objective or by decreasing focal length of eyepiece.

(ii) Resolving power of telescope is given by

$$\text{RP} = \frac{1}{d\theta} = \frac{D}{1.22\lambda}$$

So, the resolving power can be increased by increasing diameter of objective lens or by decreasing the wavelength of light.

141. In a regular prism, what is the relation between angle of incidence and angle of emergence when it is in the minimum deviation position?

Ans : **Main 2017**

Relation between angle of incidence and angle of emergence :

$$i + e = A + \delta$$

where

i = is the angle of incidence

e = is the angle of emergence

A = is Prism Angle

δ = is deviation angle

When angle of incidence is equals to angle of emergence ($i = e$) then prism will be in the minimum deviation position.

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142. Obtain an expression for refraction at a single convex spherical surface, i.e. the relation between μ_1 (rarer medium), μ_2 (denser medium), the object distance u, image distance v and radius of curvature R.

Ans : **Main 2011, 2009**

Let O be a point object in the rarer medium of refractive index u_1 and lying on the principal axis. The image of this object. O is formed by refraction at the convex spherical surface of radius at the point l into the medium B of refractive index u_2 of curvature as shown in the fig. The convex surface has a small aperture and the angles of incidence z and refraction r are small.

Let $\angle AOP = \alpha$

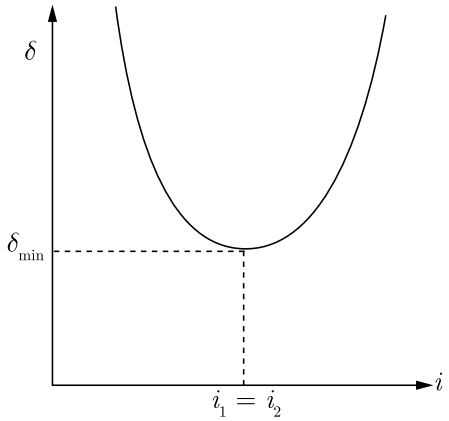
$\angle AIP = \beta$

and $\angle ACP = \gamma$

143. Draw a labelled graph of angle of deviation (δ) versus angle of incidence (i) of a prism.

Ans : **Main 2020, 2005**

Graph between angle of deviation (δ) versus angle of incidence (i) of a prism.



144. Use mirror equation to show that convex mirror always produces a virtual image independent of the location of the object.

Ans : **Main 2015**

From equation, $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$

$u < 0$, i.e., always negative for the object position in front of convex/concave mirror, $f > 0$, i.e., focal length is always positive for a convex mirror.

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u}$$

$$v \quad \frac{fu}{u - f}$$

On using sign convention,

$$v = \frac{(+f)(-u)}{(-u) - (+f)}$$

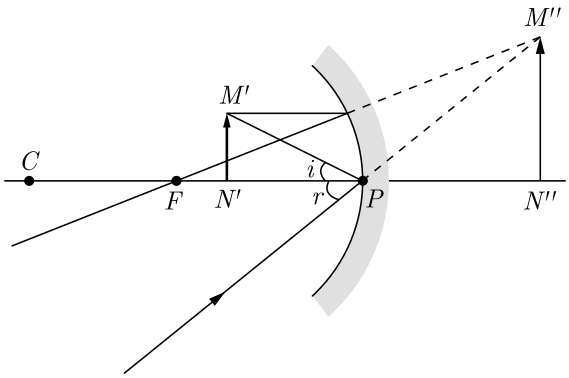
$$v = +ve$$

$$v > 0$$

145. Draw a ray diagram to show the image formation by a concave mirror. When the object is kept between its forms and the pole. Using this diagram. Derive the magnification formula for the image formed.

Ans : **Comp 2011**

Ray diagram of image formation by a concaver mirror.



In $\Delta M'N'P'$ and $M''N''P$

$$\frac{M''N''}{M'N'} = \frac{N''P}{N'P}$$

By sign conversion,

$$PN' = -u$$

$$PN'' = +v$$

$$M'N' = h_1$$

146. What is the cause of spherical aberration in lenses? State a method to minimise the defect.

Ans : **Main 2006**

The cause of the spherical aberration in lens is that the focal lengths of different zones of the lens are different.

The focal length of the middle portion of the lens is more as compared with the near edge of the lens.

Due to this all the rays passing through the lens are not focussed at a single point, so the image formed is blurred.

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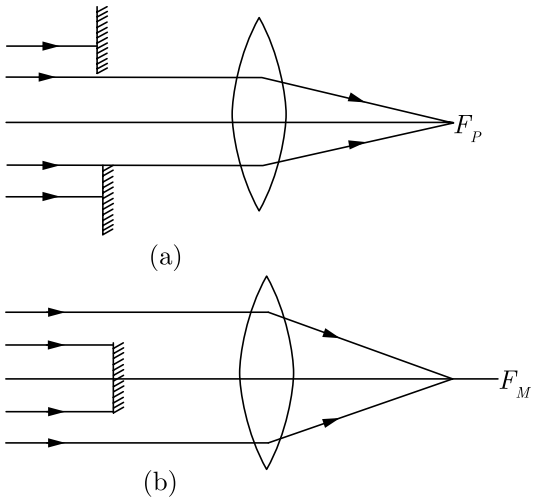
Hence, the inability of the lens to form a point image of an axial point object is called spherical aberration.

The spherical aberration can be minimise by using stops in the way of marginal or the par-axial rays or by cutting-off



Minimising spherical oberrations using stops

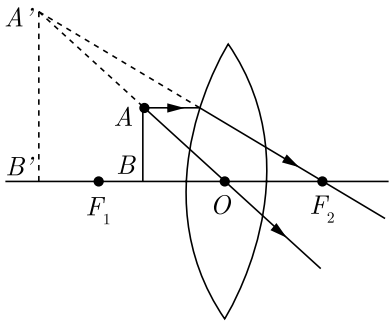
147. Where will you keep an object in front of a

(i) convex lens in order to get a virtual and magnified image?

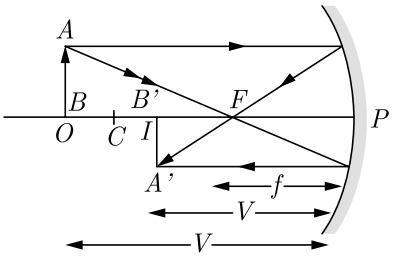
(ii) concave mirror to get a real and diminished image?

Ans : **Main 2020**

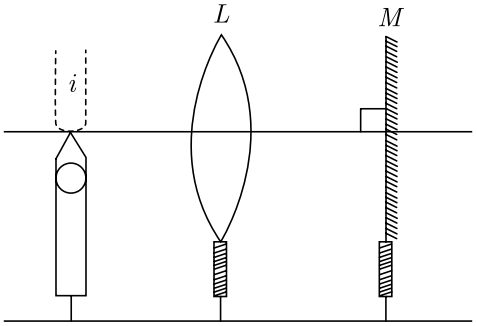
(i) To get a virtual, magnified image of an object from convex lens, we have to keep the object between optical centre and focus of the lens.



(ii) To get a real, diminished image of an object from a concave mirror, the object has to be kept beyond centre of curvature C.



148. A convex lens L and a plane mirror M are arranged as shown in the figure alongside.

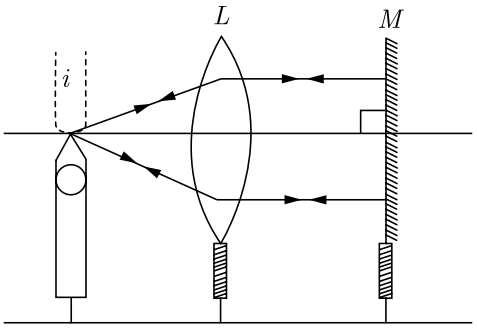


Position of object pin O is adjusted in such a way that the inverted image I formed by the lens mirror combination coincides with the object pin O. Explain how and when this happens.

Ans : **Main 2013, 2011**

Consider the ray diagram shown in the figure. It is clear from the figure that, when the object pin O lies in the focal plane of the lens L, the rays of light starting from O after refraction from the lens become parallel to the principal axis of the lens and therefore they strike normally on the plane mirror M kept behind the lens at a small distance.

Due to normal incidence $(i = 0)$, angle of reflection $r = 0^\circ$, i.e. the rays are reflected back by the plane mirror on the same path and then they enter the lens as a parallel beam. The lens converges these rays in its focal plane, hence image I is formed just above the object pin O. The image I is inverted, real and of same size as that of the object O as shown in figure.



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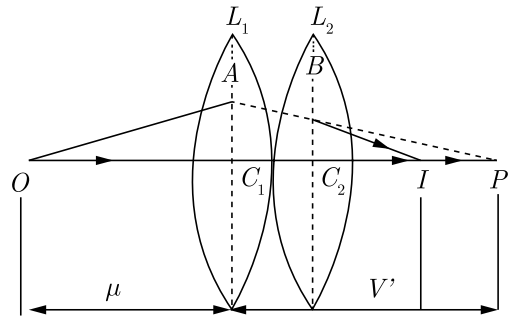
149. When two thin lenses of focal lengths f_1 and f_2 are kept co-axially and in contact, prove that their combined focal length f is given by

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$$

Ans : **Main 2014, 2008**

Suppose C_1, C_2 be the optical centres of two thin convex lenses L_1 and L_2 held co-axially in contact with each other in air.

Suppose f_1 and f_2 are their respective focal lengths as shown in the figure.



Let a point object O be placed on the common principal axis at a distance $OC_1 = u$. The lens L_1 alone would form its image at I, where $C_1I' = v'$. From the lens formula,

$$\frac{1}{v'} - \frac{1}{u} = \frac{1}{f_1} \quad ...(1)$$

I' would serve as a virtual object for lens L_2, which forms a final image I at distance $C_2I = v$.

Since, the lenses are thin, therefore, for the lens

$$L_2,\ u = C_2I' \approx C_1I' = v'$$

From the lens formula for L_2,

$$\frac{1}{v} - \frac{1}{v'} = \frac{1}{f_2} \quad ...(2)$$

On adding Eqs. (1) and (2), we get

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f_1} + \frac{1}{f_2} \quad ...(3)$$

Let the two lenses be replaced by a single lens of focal length f, which forms image I at distance v, of an object at distance u from the lens. For this lens,

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \quad ...(4)$$

From Eqs. (3) and (4), we get

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$$

THREE MARKS QUESTIONS

150. State the advantages of reflecting telescope over refracting telescope.

Ans : **Main 2015**

Advantages

(i) There is no chromatic aberration in a mirror.

(ii) Brighter image.

(iii) High resolving power.

(iv) Large magnifying power.

151. Write the expression for resolving power of a compound microscope. How can the resolving power of a microscope be increased ?

Ans : **Main 2014**

Resolving power of compound microscope

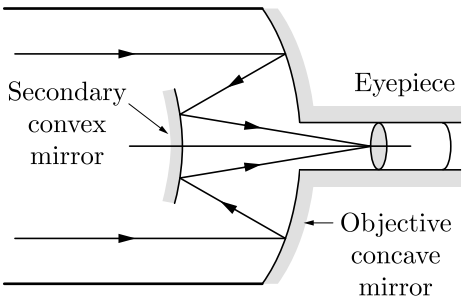
$$= \frac{2\mu \sin\beta}{1.22\lambda}$$

Where $\mu =$ Refractive index of the medium between the object and the objective lens.

Resolving power can be increased by decreasing wavelength and by increasing refractive index of medium.

152. Draw a schematic labelled ray diagram of a reflecting type telescope (cassegrain).

Ans : **SQP 2014, 2016**



153. A convex lens is placed over a plane mirror. A pin is positioned so that there is no parallax between the pin and its image formed by this lens-mirror combination. How will you use this observation to find focal length of the lens? Explain briefly.

Ans : **SQP 2014**

Focal length = distance of the pin from the mirror.

The rays from the object after refraction from lens should fall normally on the plane mirror. So, they retrace their path. Hence, rays must be originating from focus and thus distance of the pin from the plane mirror gives focal length of the lens.

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154. The objective of telescope is a larger focal length and of larger aperture (compared to the eyepiece.) Why ? Given reasons.

Ans : **Main 2010**

In normal adjustment, magnifying power of the telescope, $M = \frac{f_o}{f_e}$.

(i) If focal length of the objective lens is large in comparison to the eyepiece, magnifying power increases.

(ii) Resolving power of the telescope $RP = \frac{D}{1.22\lambda}$
D being the diameter of the objective.
To increase the resolving power of the telescope, large aperture of the objective lens is required.

155. Define magnifying power of an optical instrument. An astronomical refracting telescope consists of two lenses of focal lengths 75 cm and 5 cm. Calculate the magnifying power of the telescope, when the final image is formed at a distance of 25 cm from the eye.

Ans : **Main 2025**

The magnifying power or the angular magnification of an optical instrument is defined as the ratio of the angle subtended by the image at the eye to the angle subtended by the object at the unaided eye.

Magnifying power of the telescope

$$M = \frac{f_o}{f_e}\left(1 + \frac{f_e}{D}\right)$$
$$= \frac{75}{5}\left(1 + \frac{5}{25}\right) = 15$$

156. A prism can produce spectrum of white light but a glass slab having same material as prism cannot produce any spectrum. Why?

Ans : **SQP 2008, 2006**

In case of a prism, when white light is incident on it, the white light break up into constituent colours. And the emergent light is not parallel to incident light, so the different colours for deviation at different angles and we get a spectrum of white light.

In case of glass slab, when white light is incident on it, it also break up into its constituent colours, after refraction in the glass slab, but the emergent ray is parallel to incident ray, so all the different colours are deviated through same angle and image formed is white in colour and no spectrum of white light is observed.

157. How does a combination of lenses affect the size, position and nature of the image?

Ans : **Comp 2006**

Two or more lenses may be combined by placing them in contact or at a finite distance apart. We can find size, nature and position of the final image by considering refraction through individual lenses. The image formed by first lens acts as an object for second lens. Similarly, the image formed by second lens acts as an object for third lens and so on. The standard formula can be applied in case of individual lenses to obtain the final size, nature and position of the image.

If m_1 m_2, m_3 ..... are the magnifications produced by the individual lenses, then total magnification produced by the combination is,

$$M = m_1 \times m_2 \times m_3 \times .....$$

158. How is the working of a telescope different from that of a microscope?

Ans : **Main 2017**

Difference in working of telescope and microscope

(i) Objective of telescope forms the image of a very far off object at or within the focus of its eyepiece. The microscope does the same for a small object kept just beyond the focus of its objective.

(ii) The final image formed by a telescope is magnified relative to its the seen by the unaided eye while the final image formed by a microscope is magnified relative to its absolute size.

(iii) The objective of a telescope has large focal length and large aperture while the corresponding parameters for a microscope have very small values.

159. A mobile phone lies along the principal axis of a concave mirror. Show with the help of suitable diagram the formation of its image. Explain why magnification is not a uniform.

Ans : **Comp 2007**

They ray diagram for the formation of the image of the phone is shown as below. The image of the part which is on the plane perpendicular to the principal axis will be on the same plane. It will be of the same size,

i.e., $B'C = BC$

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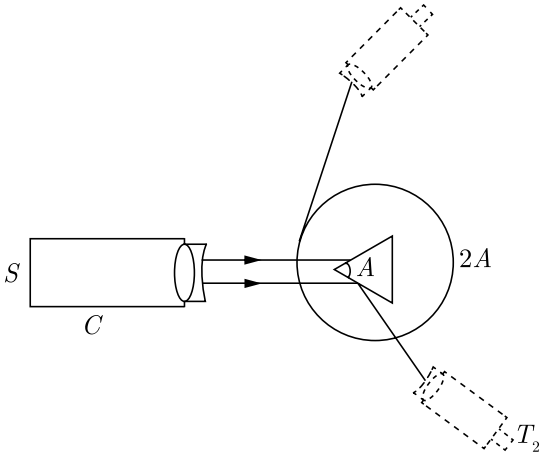
168. Draw a ray diagram illustrating the measurement of the angle of a prism using a spectrometer.

Ans : **SQP 2005**

Measuring the angle of a prism The spectrum can be used to measure angle of a prism. The spectrometer is levelled and adjusted for parallel rays. The telescope is rotated for different positions T_1 and T_2. The images of the slit is coincided with vertical cross wire.

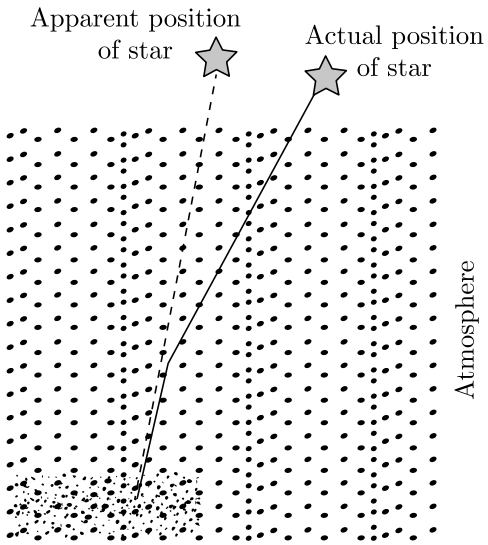
The difference of angular position for two positions T_1 and T_2 is calculated as $2A$, where A is the angle of prism.



169. How will you explain twinkling of stars?

Ans : **Comp 2018**

Unless a star is directly above and the rays from it are normal to the atmosphere, atmospheric refraction causes an angular displacement of nearly $\frac{1^\circ}{2}$ and a star is not where it appears to be (Figure). This effect has to be taken into account by astronomers and navigators.



The atmosphere consists of several moving masses of air, some hot and some cold, some dense and some rarer. When light from a distant star enters the Earth's atmosphere, it is bent as it passes from one mass of air to another. The masses themselves are in motion. This gives rise to the twinkle in stars.

170. Draw a labelled ray diagram to show the image formation by an astronomical telescope in the near point adjustment.

Ans : **Main 2014**

Image of the near object can be formed at infinity or at D.

Image of near object at infinity,

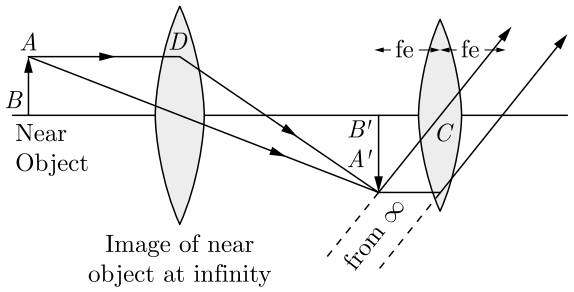
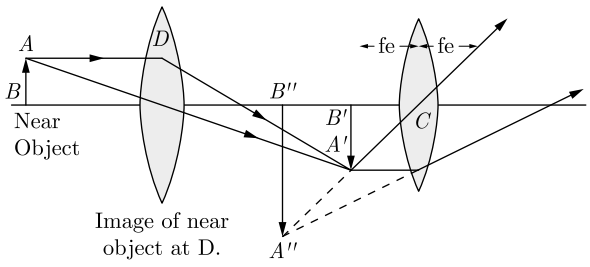


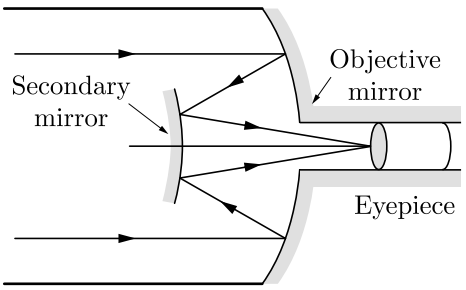
Image formed at least distance of distinct vision.



171. Draw a schematic arrangement of a reflecting telescope showing how rays coming from a distant object are received at the eyepiece. Write its two important advantages over a refracting telescope.

Ans : **Main 2018, 2016**

Diagram of a reflecting telescope (Cassegrain) is shown as below



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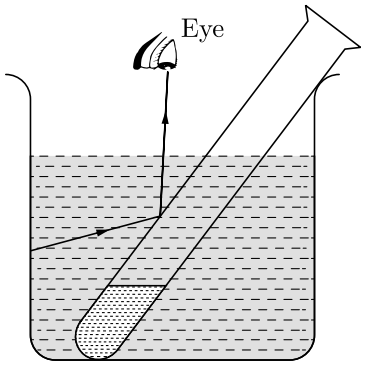
164. An empty test tube is placed slanting in the water and viewed from above. What will you observe?

Ans : **Main 2012**

The portion of the tube within water will shine like a mirror due to total internal reflection. If the tube is partially filled with water, the portion of tube containing water will no linger show this effect.

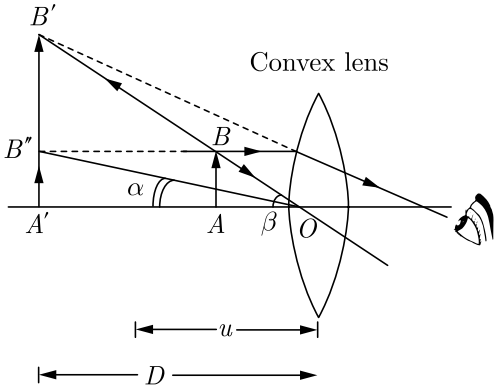


165. Draw a neat labelled ray diagram of a simple microscope when the image is formed at the least distance of distinct vision D. Write the expression for its angular magnification (magnifying power) in this set-up. [Derivation of formula is not required.]

Ans : **Main 2022 Sem-II**

Microscope is an optical instrument which forms a large image of close and minute objects. A simple microscope is a converging lens (convex lens) of small focal length' Simple microscope is based on the principle that, when an object is placed at a distance less than the focal length of the lens, the image obtained is virtual, erect and magnified.

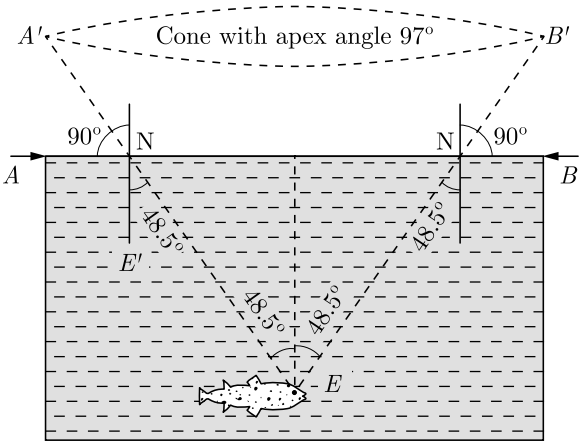
Consider the diagram shown below The final image i is formed at $D(AB)$ for the object AB.



166. How does the surface of the earth appear to a fish or a person sitting inside clear water?

Ans : **SQP 2015**

Whole of the earth will appear to lie within 97° instead of actual 180°. A ray of light from A incident at angle of 90° at N will go towards NE at an angle of 48.5°. [Refractive index of water is 1.33 and critical angel is 48.5°]. It shall appear to fish to came from A instead of A′. Similarly, another ray from B will appear to come from B′. Whole of the earth will appear to lie within a cone of apex angle $48.5° + 48.5° = 97°$.

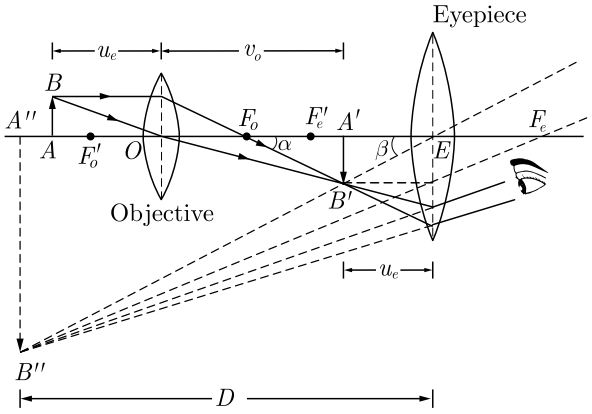


167. Draw a labelled diagram of an image formed by a compound microscope with image at least distance of a distinct vision.

Ans : **Main 2015, 2013, 2011**

While drawing the labelled diagram of the compound microscope, we must form final image at the least distance of distinct vision (D).

Consider the image formation by the compound microscope.



In the above diagram, AB = object and $A''B''$ = final image

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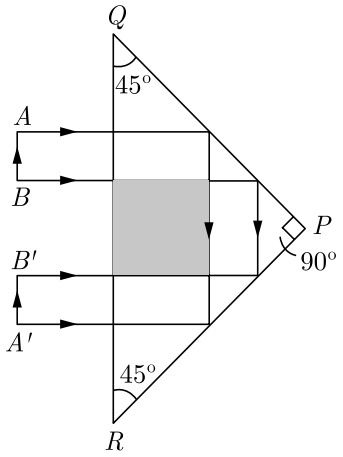
(ii) Deviation of light rays through 180°.



175. Show that the axial chromatic aberration $(f_R - f_V)$ for a convex lens is equal to the product of its mean focal length (f) and dispersive power of its material i.e. prove $f_R - f_V = \omega f$.

Ans : **Main 2013, 2009**

We have to apply lens maker's formula corresponding to each colour and then find required ratios. Suppose the mean refractive index of the material of the lens be ply and the mean focal length of the lens be f_Y. Then, from lens formula, we have

$$\frac{1}{f_Y} = (\mu_Y - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad ...(1)$$

Similarly, for the red and violet lights, we have

$$\frac{1}{f_R} = (\mu_R - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad ...(2)$$

and $$\frac{1}{f_V} = (\mu_V - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad ...(3)$$

From Eqs. (2) and (3), we get

$$\frac{1}{f_V} - \frac{1}{f_R} = (\alpha_V - \alpha_R)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\frac{1}{f_V} - \frac{1}{f_R} = \left(\frac{\alpha_V - \alpha_R}{\alpha_Y - 1}\right)\frac{1}{f_Y} \quad \text{[from Eq. (1)]}$$

or $$\frac{f_R - f_V}{f_V f_R} = \left(\frac{\alpha_V - \alpha_R}{\alpha_Y - 1}\right)\frac{1}{f_Y}$$

Since, f_V, f_R and f_Y differ only slightly, we can substitute iv in the place of $f_V f_R$.

Then, we have

$$\frac{f_R - f_V}{f_Y^2} = \left(\frac{\alpha_V - \alpha_R}{\alpha_Y - 1}\right)\frac{1}{f_Y}$$

or $$f_R - f_V = \left(\frac{\alpha_V - \alpha_R}{\alpha_Y - 1}\right) f_Y$$

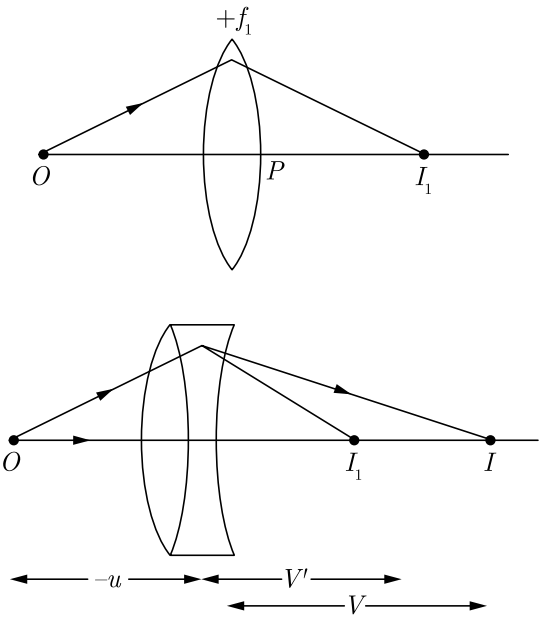
$\left(\frac{\alpha_V - \alpha_R}{\alpha_Y - 1}\right)$ is the dispersive power of the material of the lens and is denoted by ω.

Thus, the axial chromatic aberration (where object is at infinity) of the lens is given by

$$f_R - f_V = \omega \times f_Y$$

176. A convex lens of focal length f_1 is kept in contact with a concave lens of focal length f_2. Find the focal length of the combination.

Ans : **SQP 2006**



For convex lens of focal length $+(f_1)$

$$+\frac{1}{f_1} = \frac{1}{v} - \frac{1}{u} \quad ...(1)$$

For convex lens of focal length $(-f_2)$

$$-\frac{1}{f_2} = \frac{1}{v} - \frac{1}{v'} \quad ...(2)$$

Adding equation (1) and (2)

$$\frac{1}{f_2} - \frac{1}{f_2} = \frac{1}{v} - \frac{1}{u} \quad ...(3)$$

For an equivalent lens (Using lens formula)

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \quad ...(4)$$

where, f is the focal length of combination

From equation (3) and (4),

$$\frac{1}{f} = \frac{1}{f_1} - \frac{1}{f_2}$$

177. Draw the diagrams to show behaviour of plane wave-fronts as they (a) pass through a thin prism, and (b) pass through a thin convex lend and (c) reflect by a concave mirror.

Ans : **SQP 2014, 2012**

The behaviour of a thin prism and a thin convex lens are shown in figs (a) and (b) respectively.

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Advantages of reflecting telescope over a refracting telescope are given as below

(i) A reflecting telescope reflects all wavelengths of light at the same angle, so there are no colour halos.

(ii) A mirror has only one surface to be figured, so it is easier to control the shape.

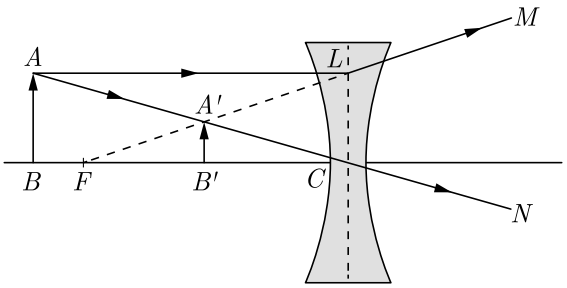
(iii) A mirror reflects the light, so the material that is made from does not have to be transparent and infrared and ultraviolet light reflects equally well.

172. Describe the formation of image by a concave lens.

Ans : **SQP 2009**

Let us consider a concave mirror of focal length F and optical centre C as shown in figure. Let, a ray of light AL be incident parallel to the principal axis of the concave lens and is refracted along LM. When this ray is produced in backward direction it meets at F, i.e. the ray LM appears to be coming from the focus F. Other ray AN which passes through the optical centre C of the concave lens, goes undeviated and these two refracted rays meet at A'. So $A'B'$ is the virtual image of object AB.

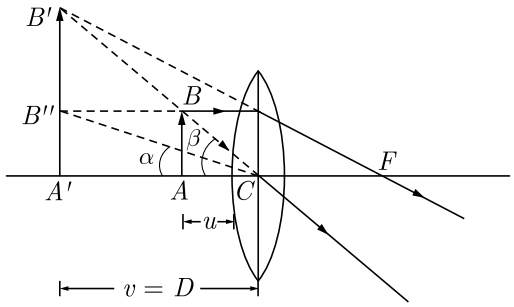
Here, the image is always virtual (independent of position of object), erect, diminished and is formed infront of the lens. If the object is moved closer to the lens, the image moves towards the optical centre is always formed in front of the lens.



173. Draw neat ray diagram of a simple microscope. Deduce the formula for angular magnification, when the image is formed at the least distance of distinct vision.

Ans : **Main 2002**

The ray diagram of a simple microscope is shown below.



Angular magnification,

$$M = \frac{\beta}{\alpha}$$

If angle are small, $\beta \simeq \tan\beta$, $\alpha \simeq \tan\alpha$

Hence, $$M = \frac{\tan\beta}{\tan\alpha} = \frac{AB/AC}{A'B''/A'C}$$

$$A'B'' = AB$$

$$M = \frac{A'C}{AC} = \frac{v}{u}$$

We know that, $$\frac{v}{u} = 1 - \frac{v}{f} \qquad [\text{but } v = -D]$$

$$M = 1 - \left(-\frac{D}{f}\right) = 1 + \frac{D}{f}$$

174. State the necessary conditions for producing total internal reflection of light. Draw ray diagrams to show specially designed prism make use of total internal reflection to obtain inverted image of the object by deviation of rays

(i) thought 90° and (ii) thought 180°.

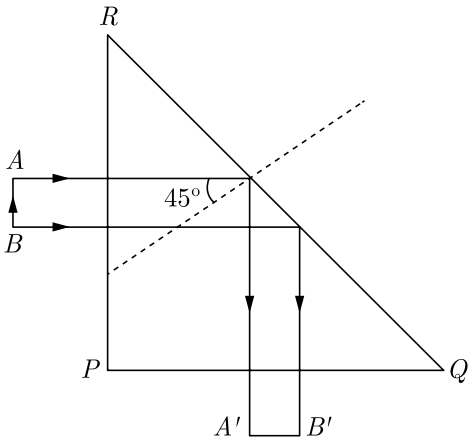
Ans : **Main 2024**

Following are the criteria for total internal refection

(a) Light must pass from a denser to a rarer medium.

(b) Angle of incidence must be greater than critical angle.

(i) Deviation of light rays through 90°.



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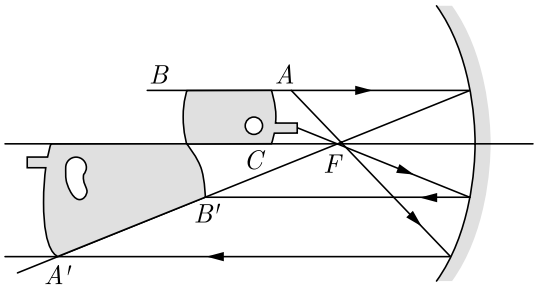
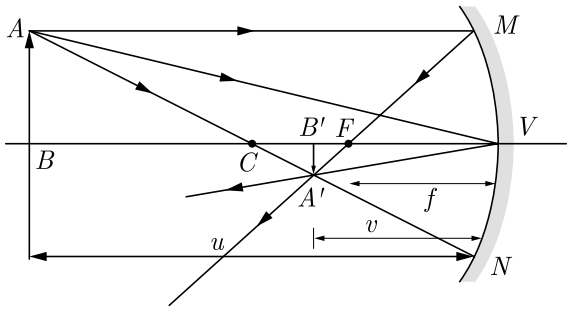


160. Suppose the lower half of the concaver mirror's reflecting surface is covered with an opaque material. What effect this will have on the image of the object? Explain.

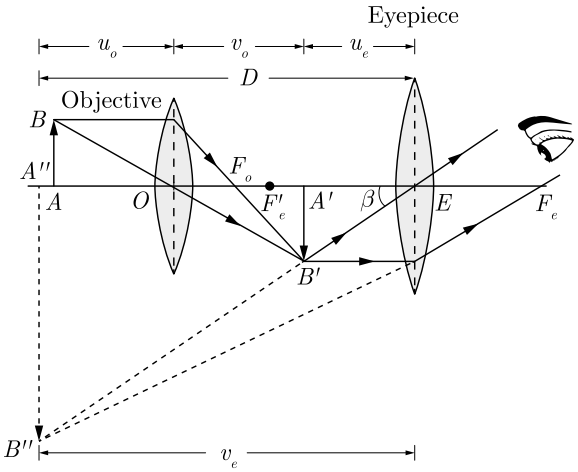
Ans : **Main 2011**

We may think that the image will now show only half of the object, but considering the laws of reflection to be true for all points of the remaining part of the mirror, the image will be the of the whole object. However, as the area of the reflecting surface has been reduced, the intensity of the image will be low, i.e., half.



161. Draw a schematic ray diagram of a compound microscope when image is formed at distance of distinct vision.

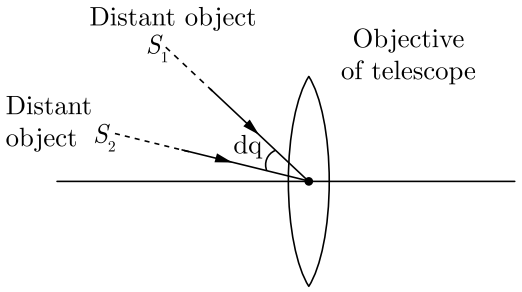
Ans : **SQP 2007**



162. What is meant by resolving power of a telescope?

Ans : **Main 2017**

The resolving power of a telescope is defined as the reciprocal of the smallest angular separation between two distant objects whose images are seen separately.



$$\text{Resolving power} = \frac{1}{d\theta} = \frac{D}{1.22\lambda} \qquad \text{(aperture)}$$

Resolving power depends on

(a) wavelength λ and

(b) diameter (aperture) of the objective D.

163. Two convex lenses of same focal length but of apertures A_1 and A_2 $(A_2 < A_1)$, are used as the objective lenses in two astronomical telescopes having identical eyepieces. What is the radio of their resolving power? Which telescope will you prefer and why? Give reason.

Ans : **Comp 2010, 2003**

Resolving power of telescope,

$$R_p = \frac{A}{1.22\lambda}$$

where, A = aperture or diameter of the objective telescope

and λ = wavelength of the objective.

$$R \propto A$$

Hence, Ratio of resolving powers of two telescopes

$$\frac{R_1}{R_2} = \frac{A_1}{A_2}$$

Since, $A_2 > A_1$

Hence, $R_2 > R_1$

The larger the aperture of objective, higher the resolving power of telescope. As well more gathering of light to form the image and hence, brighter image would be obtained.

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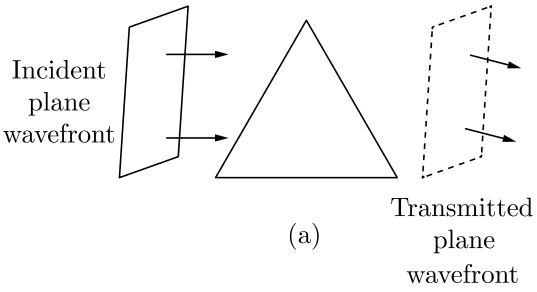
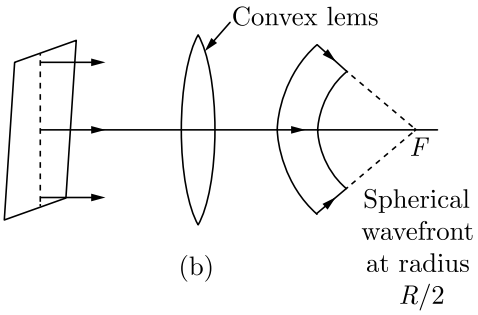
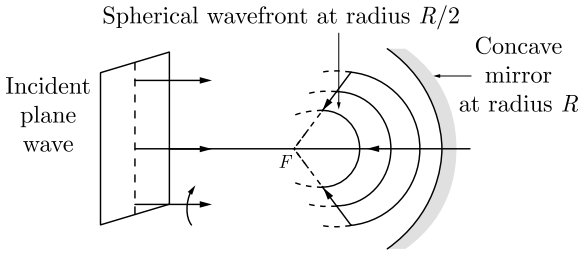


(a)



(b)

A plane wave front becomes spherical convergent after refection



(c)

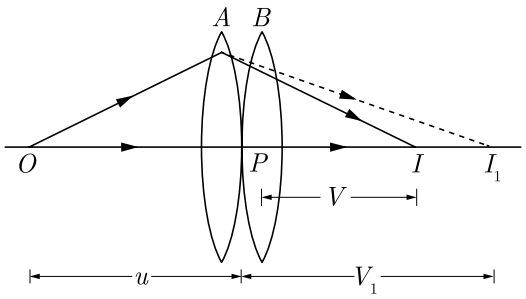
178. Define power of a lens. Write its units. Deduce the relation $\frac{1}{f} = \frac{1}{f_1} - \frac{1}{f_2}$ for two thin lenses kept in contact coaxially.

Ans : **Comp 2017, 2012**

The power of a lens is equal to the reciprocal of its focal length when it is measured in metre. Power of a lens,

$$P = \frac{1}{f(\text{metre})}$$

It's SI unit is dioptre (D),



Consider two lenses A and B of focal lengths, f_1 and f_2 placed in contact with each other. An object is placed at a point O beyond the focus of the lens A.

The first lens produces an image (real image) at I_1, which serves as a virtual object for the second lens B producing final image at I.

Since, the lenses are thin, we assume the optical centres P of the lenses to be coincident. For the image formed by the first lens A, we obtain

$$\frac{1}{u_1} - \frac{1}{u} = \frac{1}{f_1} \quad ...(1)$$

For the image formed by the second lens B, we obtain

$$\frac{1}{v} - \frac{1}{v_1} = \frac{1}{f_2} \quad ...(2)$$

Adding eqs. (1) and (2), we obtain

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f_2} + \frac{1}{f_2} \quad ...(3)$$

If the two lenses system is regarded as equivalent to a single lens of focal length f, we have

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \quad ...(4)$$

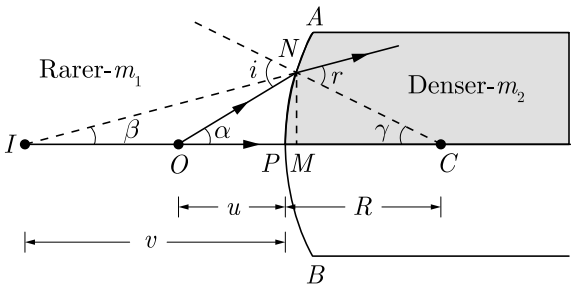
From eqs. (3) and (4), we obtain

$$\frac{1}{f} + \frac{1}{f_2} = \frac{1}{f}$$

179. With the help of a suitable ray diagram, derive a relation between the object distance (u), image distance (v) and radius of curvature R for the convex spherical surface when a ray of light travels from a rarer to denser medium.

Ans : **Main 2012**

Let an object O is placed at a distance u from convex S spherical refracting surface whose virtual image formed at I at a distance v form surface. Let R is the radius of curvature of surface



In ΔONC, $i = \alpha + \gamma$ ...(1)

In ΔINC, $r = \beta + \gamma$ ...(2)

Also, for small angle α, β and γ

$$1\alpha \simeq \tan\alpha = \frac{NM}{OM} \simeq \frac{NM}{PO}$$

$$= \frac{h}{-u} \quad ...(3)$$

[Minimum close to P]

Where, $h = NM$

$$\beta \simeq \tan\beta = \frac{NM}{IM} \simeq \frac{NM}{PI} = \frac{h}{-v} \quad ...(4)$$

Also, $$\gamma \simeq \tan\gamma = \frac{NM}{MC} \simeq \frac{NM}{PC} = \frac{h}{+R} \quad ...(5)$$

But, by Snell's law,

$$\frac{\sin i}{\sin r} = \frac{n_2}{n_1}$$

where n_2, n_1 are the refractive indices of denser medium and rarer medium, respectively.

Since, Angles i and r are small.

Hence, $$\sin i \simeq i, \sin r = r$$

$$\frac{i}{r} = \frac{n_2}{n_1}$$

$$n_1 i = n_2 r$$

Hence, $$n_1(\alpha+\gamma) = n_2(\beta+\gamma)$$

[from eqs.(1) and (2)]

$$n_1\alpha - n_2\beta = \gamma(n_2 - n_1)$$

$$n_1\left(\frac{h}{-u}\right) - n_2\left(\frac{h}{-v}\right) = \left(\frac{h}{+R}\right)(n_2 - n_1)$$

[from eqs.(4) and (5)]

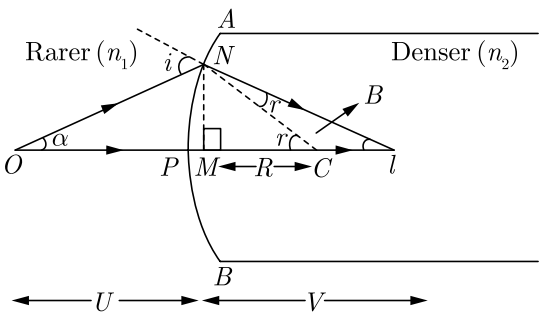
$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$$

This is the required expression.

180. Obtain an expression for refraction at a single convex spherical surface separating the two media having refractive indices n_1 (rarer medium) and n_2 (denser medium) i.e. a relation between u, v, n_1, n_2 and R.

Ans : SQP 2018

Let APB is a convex refracting surface which separates a rarer and a denser medium having refractive indices n_1 and n_2



where, i = angle of incidence

and r = angle of refraction

Now in ΔNOC

$$i = \alpha + \gamma$$

Similarly in ΔNIC

$$\gamma = r + \beta \text{ or } r = \gamma - \beta$$

Suppose all rays are par-axial, then the angles i, r, α, β and γ are small.

$$\alpha \approx \tan\alpha = \frac{NM}{OM} \approx \frac{NP}{OP}$$

[P is close to M]

$$\beta \approx \tan\beta = \frac{NM}{MI} \approx \frac{NM}{PI}$$

$$\gamma = \tan\gamma = \frac{NM}{MC} \approx \frac{NM}{PC}$$

From Snell's law,

$$\frac{\sin i}{\sin r} = \frac{n_2}{n_1}$$

If i and r are small, then

$$\frac{i}{r} \approx \frac{n_2}{n_1} \text{ or } n_1 i = n_2 r$$

Or $$n_1(\alpha+\gamma) = n_2(\gamma-\beta)$$

$$n_1\left[\frac{NM}{OP} + \frac{NM}{PC}\right] = n_2\left[\frac{NM}{PC} - \frac{NM}{PI}\right]$$

$$n_1\left[\frac{1}{OP} + \frac{1}{PC}\right] = n_2\left[\frac{1}{PC} - \frac{1}{PI}\right]$$

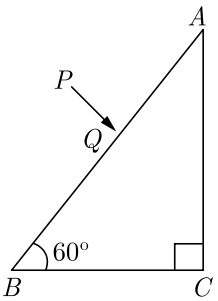
$$\frac{n_1}{OP} + \frac{n_2}{PI} = \frac{n_2 - n_1}{PC}$$

Using sign convention

$$-\frac{n_1}{u} + \frac{n_2}{v} = \frac{n_2 - n_1}{R}$$

or $$\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$$

181. A ray PQ incident normally on the refracting face BA is refracted in the prism BAC made of material of refractive index 1.5. Complete the path of ray through the prism. From which face will the ray emerge? Justify your.



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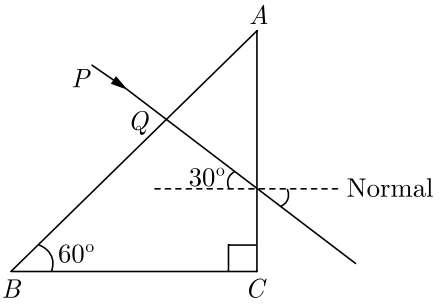
Ans : SQP 2017



For face, $AB, \angle i = 0^\circ$

i.e., $\angle r = 0^\circ$

They ray will pass through AB

Now, at face AC

Here, $i_c = \sin^{-1}\left(\frac{1}{\mu}\right)$

$= \sin^{-1}\left(\frac{2}{3}\right) = \sin^{-1}(0.66)$

$\angle i$ on face AC is 30° which is less than $\angle i_c$. Hence, they ray get refracted.

and applying Snell's law at face AC

$\sin 30^\circ \times \frac{3}{2}\ \sin r \times 1$

$\sin r = \frac{1}{2} \times \frac{3}{2}$

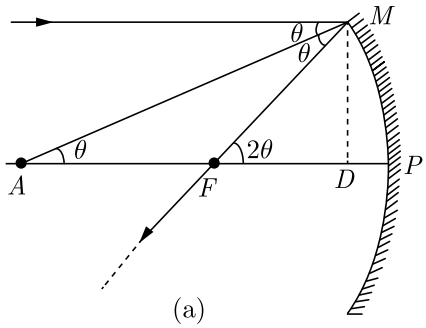
$r\ \sin^{-1}\left(\frac{3}{4}\right) = \sin^{-1}(0.75)$

and clearly $r > i$, as ray passes from denser to rarer medium.

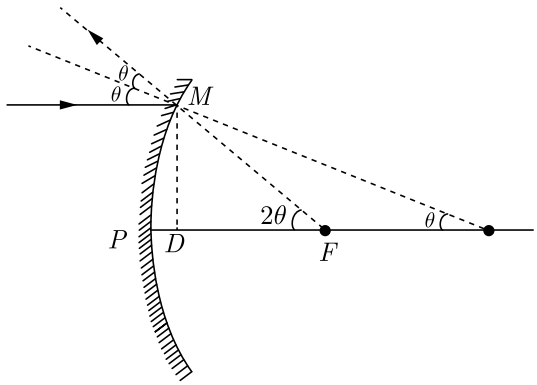
182. Derive R = $2f$ for a spherical mirror, where the symbols have their usual meaning.

Ans : SQP 2014

Consider a ray parallel to the principal axis striking the mirror at point M. Then CM will be perpendicular to the mirror at point M. Let θ be the angle of incidence and MD be perpendicular to the principal axis. Then,



(a)



(b)

Geometry of reflection of an incident ray on

(a) concave spherical mirror and

(b) convex spherical mirror

$\angle MCP = \theta$ and $\angle MFP = 2\theta$

Now, $\tan\theta = \frac{MD}{CD}$

and $\tan 2\theta = \frac{MD}{FD}$ ...(1)

For small θ (condition true for par-axial rays), $\tan\theta \approx \theta$ and $\tan 2\theta \approx 2\theta$

Therefore, from Eq.(1), we get

$\frac{MD}{FD} = 2\frac{MD}{CD}$

or $FD = \frac{CD}{2}$ ...(2)

Again, for small θ, we can observe that the point D is very close to the point P. Therefore, $FD = f$ and $CD = R$.

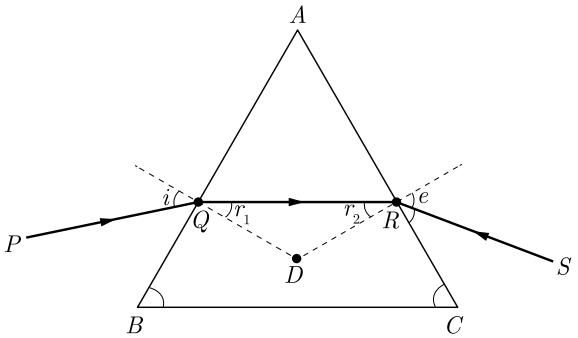
From Eq.(2), we have

$f = \frac{R}{2}$

183. Figure shows a ray of light passing through a prism. If the refracted ray QR is parallel to the base BC, show that

(i) $r_1 = r_2 = \frac{A}{2}$ and

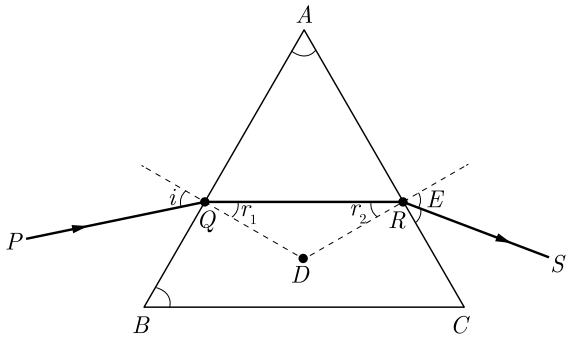
(ii) Angle of minimum deviation, $D_m = 2i - A$



NODIA

Ans : **Main 2014**

(i) When QR is parallel to the base BC, we have $i = e$



$$r_1 = r_2 = r \quad \text{(let)} \ldots(1)$$

We know that, $r_1 + r_2 = A$

From eq. (1), we get

$$2r = A, r = \frac{A}{2} \quad \ldots(2)$$

Hence, $r_1 = r_2 = \frac{A}{2}$

(ii) Also, we have

$$A + D = i + e$$

Substituting, $D = D_m$ and $e = i$

$$A + D_m = i + i$$

Hence, $D_m = 2i - A$

184. Use the mirror equation to show that

(a) an object placed between f and $2f$ of a concave mirror produces a real image beyond $2f$.

(b) a convex mirror always produces a virtual image independent of the location of the object.

(c) an object placed between the pole and focus of a concave mirror produces a virtual and enlarged image.

Ans : **SQP 2015, 2011**

(a) Mirror equation is,

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$$

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{4}$$

For a concave mirror, f is negative, *i.e.*$f < 0$.

For a real object (on the left of mirror),

For u between f and $2f$ implies $\frac{1}{f}$ and $\frac{1}{2f}$, i.e., $\frac{1}{2f} > \frac{1}{u} > \frac{1}{f}$ (as, u, f are negative)

$$-\frac{1}{2f} < -\frac{1}{u} < -\frac{1}{f}$$

$$\frac{1}{f} - \frac{1}{2f} < \frac{1}{f} - \frac{1}{u} < 0$$

$$\frac{1}{2f} < \frac{1}{v} < 0$$

i.e., $\frac{1}{v}$ is negative

This implies that v is negative and greater than $2f$ This means that the image lies beyond $2f$ and it is real.

(b) For a convex mirror, f is positive i.e., $f > 0$

For a real object on the left u is negative

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u} \text{ implies } \frac{1}{v} = \frac{1}{f} - \frac{1}{u}$$

A u is negative and f is positive, $\frac{1}{v}$ must be positive, so v must be positive, i.e., image lies behind the mirror. Hence, image is virtual whatever the value of u may be.

(c) For a mirror,

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} \quad \ldots(1)$$

For a concave mirror, f is negative $f < 0$

As u is also negative, so $f < u < 0$

This implies, $\frac{1}{f} - \frac{1}{u} > 0$

Then from eq. (1), $\frac{1}{v} > 0$ or v is positive.

i.e., image is on the right and hence virtual.

Magnification, $m = -\frac{1}{u} = -\frac{f}{u - f}$

As u is negative and f is positive, magnification

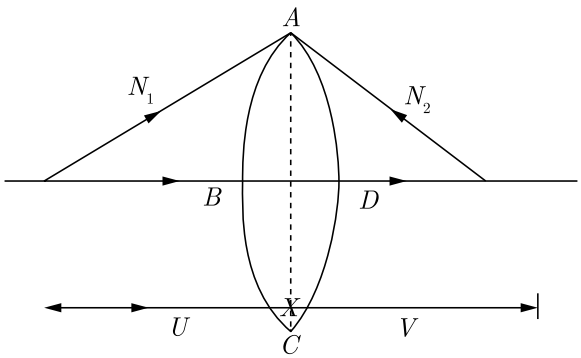
$$m = \frac{|f|}{|f| - |u|} > 1$$

i.e., image is enlarged.

185. Starting with an expression for refraction at a single spherical surface, obtain lens maker's formula.

Ans : **Main 2017, 2015**

Lens maker's formula



(a)

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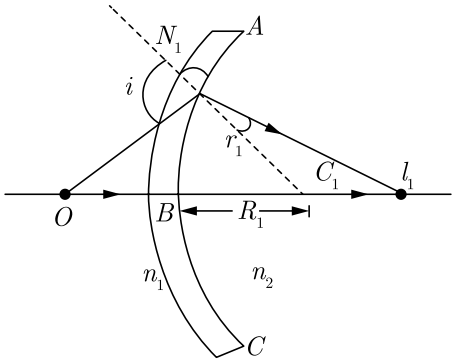
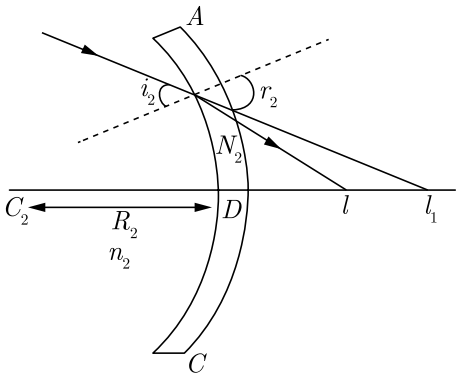


(b)



(c)

The above figure shows the image formation by a convex lens.

Applying the equation for spherical refracting surface to the first interface ABC, we obtain

$$\frac{n_1}{OB}+\frac{n_2}{BI_1}=\frac{n_2-n_1}{BC_1} \quad ...(1)$$

A similar procedure applied to the second interface ADC gives,

$$-\frac{n_2}{DI_1}+\frac{n_1}{DI}=\frac{n_2-n_1}{DC_2} \quad ...(2)$$

For a thin lens, $BI_1 = DI_1$

On adding Eqs. (1) and (2), we obtain

$$\frac{n_1}{OB}+\frac{n_1}{DI}=(n_2-n_1)\left(\frac{1}{BC_1}+\frac{1}{DC_2}\right) \quad ...(3)$$

Suppose the object is at infinity i.e.

$$OB \to \infty \text{ and } DI \to f$$

Eq. (3) can be written as

$$\frac{n_1}{f}=(n_2-n_1)\left(\frac{1}{BC_1}+\frac{1}{DC_2}\right) \quad ...(4)$$

The point where image of an object placed at infinity is formed is called the focus (f) of the lens and the distance f gives its focal length. A lens has two foci, F and F' on either side of it by sign convention.

$$BC_1 = R_1$$

or $$DC_2 = -R_2$$

Therefore, Eq. (4) can be written as

$$\frac{1}{f}=({}_1n_2-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right) \quad \left[{}_1n_2=\frac{n_2}{n_1}\right] \quad ...(v)$$

Eq. (v) is known as the lens maker's formula.

FOUR MARKS QUESTIONS

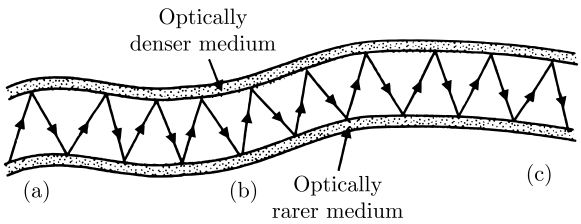
186. While studying optical communication, Priya came across optical fibres. What are optical fibres? Mention any four applications of fibre optics."

Ans : **SQP 2015**

NODIA

Optics fibres too make use of the total internal reflection principle. Optical fibres consist of many thousands of very long fine quality, glass/ quartz fibres. They are coated with a thin layer of a material of low refractive index. For example, the strand can be 0.0001 cm in diameter and the refractive index of the main fibre 1.7 an that of coating 1.5 (Figure).

When the light is incident on one end of the fibre at a small angel, the light passes inside. It undergoes repeated total internal reflections along the fibre and finally comes out. The angle of incidence here is larger than the critical angle of the fibre material with respect of its coating. Even if the fibre is bent, the light can easily travel along the fibre.



Uses of Optical Fibre :

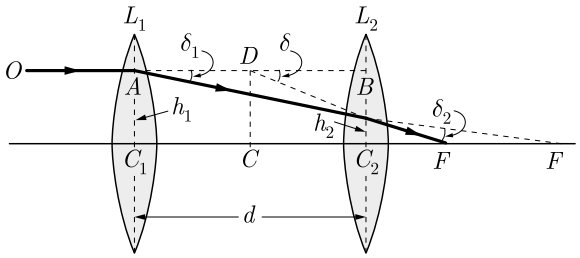
1. A bundle of optical fibres can be used as a 'light pipe' in medical and optical examination called Endoscopy.
2. It can also be used for optical signal transmission.
3. Optical fibres have also been used for transmission and receiving electrical signals which are converted to light by suitable transducers. The main requirement is that there by very little absorption of light as it

191. What do you mean by the equivalent lens? Derive an expression for the equivalent focal length of a system of two lenses placed at a certain separation.

Ans : SQP 2019, 2018

Equivalent lens : A single lens which forms the image of an object at the same position as is formed by a combination of lenses is called an equivalent lens.

Thin lenses separated by a small distance : As shown in Figure consider two thin lenses L_1 and L_2 of focal lengths f_1 and f_2, respectively. The two lenses are placed coaxially, distance 'd' apart.



Suppose a ray OA traversing parallel to the principal axis is incident on lens L_1. It is refracted along AF, F being the second principal focus of L_1. The deviation produced by L_1 is,

$$\delta_1 = \tan\delta_1 = \frac{h_1}{f_1}$$

The emergent ray is further refracted by second lens L_2 along BF'. Since the incident ray OA is parallel to the principle axis, F' should be second principal focus of the combination. The deviation produced by the second lens L_2 is,

$$\delta_2 \simeq \tan\delta_1 = \frac{h_1}{f_1}$$

The final emergent ray BF', when produced backwards, meets the incident ray at point D. Obviously, δ is the final deviation produced. A single thin lens placed at C will produce the same deviation as by the combination of two lenses. Thus distance CF' is the second focal length of the combination. If f is the focal length of the combination, then

$$\delta = \frac{h_1}{f}$$

It is obvious from figure, that

$$\delta = \delta_1 + \delta_2$$

$$\frac{h_1}{f} = \frac{h_1}{f_1} + \frac{h_2}{f_2}$$

As $\Delta AC_1F \backsim \Delta BC_2F$, therefore, we have

$$\frac{AC_1}{C_1F} = \frac{BC_2}{C_2F} \text{ or } \frac{h_1}{f_1} = \frac{h_2}{f_1 - d}$$

$$h_2 = \frac{f_1 - d}{f_1} \cdot h_1$$

Hence,

$$\frac{h_1}{f} = \frac{h_1}{f_1} + \frac{f_1 - d}{f_1 f_2} \cdot h_1$$

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$$

192. What is a lens formula? Derive an expression for lens formula for a convex lens forming a real image?

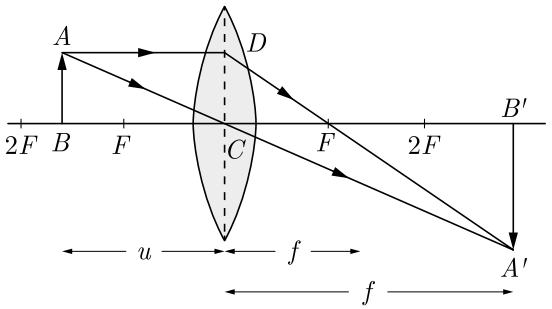
Ans : SQP 2016

Lens Formula: Lens formula is an equation relating the distance of object, distance of image formed and the focal length of the lens, and is given by,

$$-\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

Where u is the distance of object form optical centre of the lens, v is the distance of image from the optical centre of the lens and f is the focal length of the lens.

When image Formed is Real : Consider a convex lens of focal length f and optical centre C. Let an object AB be placed perpendicular to the principal axis at a point between F and $2F$. The real image of this object $A'B'$ is formed beyond $2F$ on the other side of the lens. The image is real, inverted and magnified and magnified as shown in figure.



ΔABC and $\Delta AB'C$ are similar, so we have

$$\frac{A'B'}{AB} = \frac{CB'}{CB} \quad ...(1)$$

ΔDCF and $\Delta A'B'F$ are similar, so we have

$$\frac{A'B'}{DC} = \frac{FB'}{CF}$$

But, $DC = AB$

Hence,

$$\frac{A'B'}{AB} = \frac{FB'}{CF} \quad ...(2)$$

From equations (1) and (2), we have

$$\frac{CB'}{CB} = \frac{FB'}{CF}$$

or

$$\frac{CB'}{CB} = \frac{CB' - CF}{CF} \quad ...(3)$$

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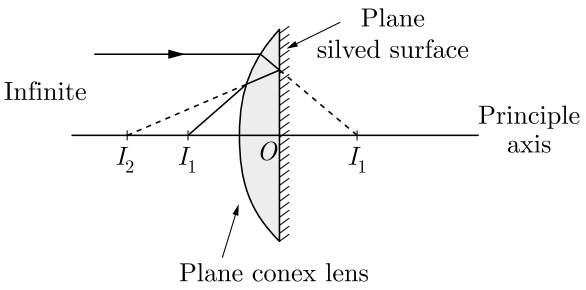
189. An object is at infinity form a planoconvex lens whose plane surface is silvered. Explain information of its image and hence find its focal length.

Ans : **Comp 2021, 2017**

According to the question,



Let the focal length of lens and mirror are f_l, and f_m respectively.

For lens,

$$\frac{1}{f_l} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Here, $R_1 = \infty$ (for plane surface)

$R_2 = -R$

μ = Refractive index of lens

$$\frac{1}{f_l} = (\mu - 1)\left[\frac{1}{\infty} - \frac{1}{(-R)}\right]$$

$$= (\mu - 1)\left(\frac{1}{R}\right)$$

$$P_l = \frac{1}{f_l} = \frac{\mu - 1}{R} \quad ...(1)$$

For Mirror, $f_m = \frac{-R}{2}$

Since, $P_m = \frac{-1}{f_m} = \frac{-2}{R}$ ...(2)

Power of lens, $P = P_l + P_m + P_l$

$$= \frac{\mu - 1}{R} + \frac{2}{R} + \frac{\mu - 1}{R}$$

$$= \frac{2(\mu - 1)}{R} + \frac{2}{R}$$

$$= \frac{2\mu}{R} - \frac{2}{R} + \frac{2}{R}$$

$$= \frac{2\mu}{R}$$

Focal length, $f = \frac{1}{P} = \frac{R}{2\mu}$

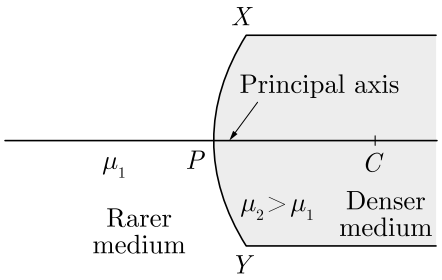
The lens will be equivalent to a converging mirror of focal length $\left(\frac{R}{2\mu}\right)$.

190. What is spherical refracting surface ? What do you mean by pole, centre of curvature, radius of curvature, aperture and principal axis.

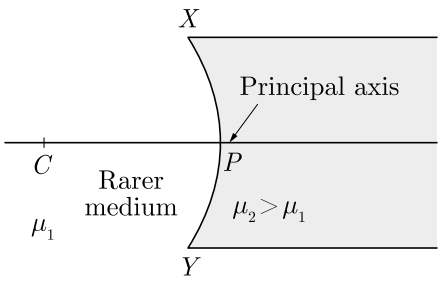
Ans : **SQP 2012**

A spherical refracting surface is formed when the refracting surface forms a part of a sphere. It is of two types.

1. **Convex spherical surface :** If the convex surface is towards the rarer medium, it is called convex spherical refracting surface, figure (a).
2. **Concave spherical surface :** If the concave surface is towards the rarer medium, it is called concave spherical refracting surface, figure (b).



(a)



(b)

1. **Pole (P) :** The centre of spherical refracting surface is called its pole.
2. **Centre of Curvature (C) :** It is the centre of the sphere from which the curved surface is taken a part.
3. **Radius of Curvature (PC) :** It is the radius of the sphere from which the curved surface is taken a part.
4. **Aperture (XY) :** The diameter of the curved surface is called its aperture.
5. **Principal Axis :** The principal axis is the line joining the pole and centre of curvature of refracting surface.

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For small angles, $\tan\theta \approx \sin\theta \approx \theta$.

So, $\angle NOM = \frac{MN}{OM}$

$\angle NCM = \frac{MN}{MC}$

$\angle NIM = \frac{MN}{MI}$

For ΔNOC, i is the exterior angle.

Hence, $i = \angle NOM + \angle NCM$

$= \frac{MN}{OM} + \frac{MN}{MC}$ ...(1)

For ΔNIC, $\angle NCM$ is the exterior angle.

Hence, $\angle NCM = r + \angle NIM$

$r = \angle NCM - \angle NIM$

i.e., $r = \frac{MN}{MC} - \frac{MN}{MI}$ ...(2)

By Snell's law,

$\mu_1 \sin i = \mu_2 \sin r$

For small angles, $\mu_1 = \mu_2$

Substituting the value of i and r from Equation. (1) and (2), we get

$\mu_1\left(\frac{MN}{OM} + \frac{MN}{MC}\right) = \mu_2\left(\frac{MN}{MC} - \frac{MN}{MI}\right)$

or $\frac{\mu_1}{OM} + \frac{\mu_1}{MI} = \frac{\mu_2 - \mu_1}{MC}$ ...(3)

Applying new Cartesian sign convention,

$OM = -u$

$MI = +v$

$MC = +r$

Substituting these values in equation (3), we get

$\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{r}$

This equation holds for any curved spherical surface.

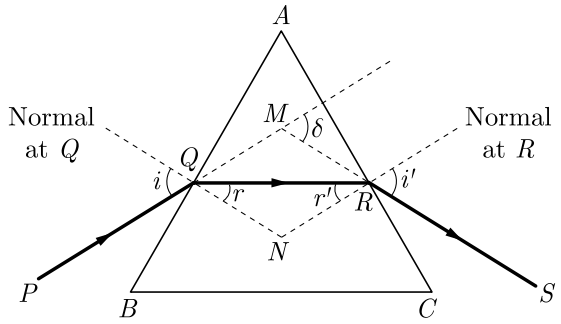
195. Show for a prism that the refractive index n is given by,

$$\eta = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

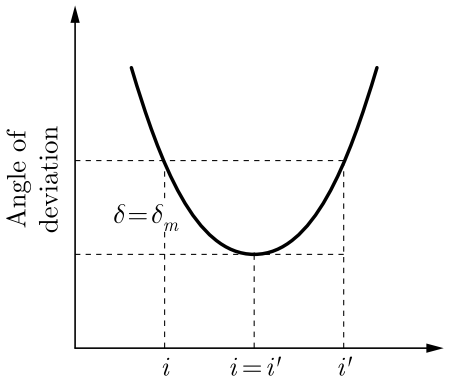
where, symbol have their usual meaning.

Ans : SQP 2020, 2015

Figure (a) shows the path of a ray of light suffering refraction through a prism of refracting angle A. Figure (b) shows the variation of angle of deviation δ with the angle of incidence i. For a given prism and for a given colour of light, the angle δ depends on i only. As i increases, the angle of δ first decreases and reaches a minimum value δ_m and then increase. Clearly, any given value of δ corresponds to two angles of incidence i and i' in the equation : $\delta = i + i' - A$ *i.e.*, δ remains the same as i and i' are interchanged. Physically, it means that the path of the ray in Figure (a) can be traced back, resulting in the same angle of deviation.



(a)



(b)

The minimum value of the angle of deviation suffered by a ray on passing through a prism is called the angle of minimum deviation and is denoted by δ_m.

Relation between Refractive Index and Angle of Minimum Deviation

When a prism is in the position of minimum deviation, a ray of light passes symmetrically (parallel to the base) through the prism so that,

$i = i'$, $r = r'$, $\delta = \delta_m$

As, $A + \delta = i + i'$

$A + \delta_m = i + i$ or $i = \frac{A + \delta_m}{2}$

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Using sign conventions,

Let, $CB' = v,\ CB = -u,\ CF = f$

So equation (3) becomes,

$$\frac{v}{-u} = \frac{v-f}{f}$$

or $$vf = -uv + uf$$

Dividing both sides by uvf, we get

$$\frac{uf}{uvf} = \frac{-uv}{uvf} + \frac{uf}{uvf}$$

$$\frac{1}{u} = -\frac{1}{f} + \frac{1}{v}$$

or $$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

This is lens formula.

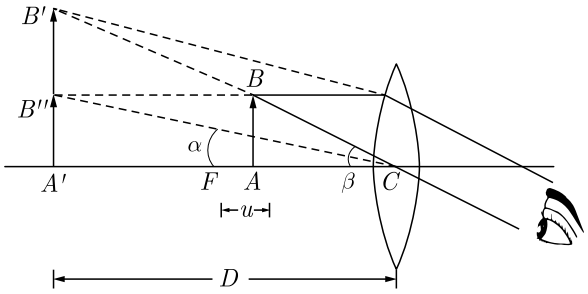
193. Draw a neat labelled ray diagram showing the formation of an image at the least distance of distinct vision D by a simple microscope. When the final image is at D, derive an expression for its magnifying power at D.

Ans : **Main 2024**

Microscope is an optical instrument which forms large image of close and minute objects. A simple microscope is a converging lens of small focal length. When an object is at a distance less than the focal length of the lens, the image obtained is virtual, erect and magnified.

When the object is at a distance equal to the focal length of the lens, the image is formed at infinity.

When the image is formed at the near point



The angular magnification or magnifying power of a simple microscope is defined as the ratio of the visual angle β subtended at the eye by image at the near point to the visual angle a subtended at the unaided eye by the object at the near point.

Magnifying power, $$m = \frac{\beta}{\alpha} \quad ...(1)$$

In $\Delta A'B'C$, $\tan\beta = \frac{A'B'}{D}$

In $\Delta A'B''C$, $\tan\alpha = \frac{A'B''}{D} = \frac{AB}{D}$

Since, the angles are small, then $\tan\alpha \approx \alpha$ and $\tan\beta \approx \beta$

$$\beta = \frac{A'B'}{D} \text{ and } \alpha = \frac{AB}{D}$$

From Eq. (1), we have

$$m = \frac{A'B'}{D} \times \frac{D}{AB} = \frac{A'B'}{AB}$$

This gives the linear magnification produced by the lens.

It can be proved that, $\frac{A'B'}{AB} = \frac{v}{u}$

We know that, $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

Multiplying both sides by v, we have

$$\frac{v}{v} - \frac{v}{u} = \frac{v}{f} \Rightarrow 1 - m = \frac{v}{f}$$

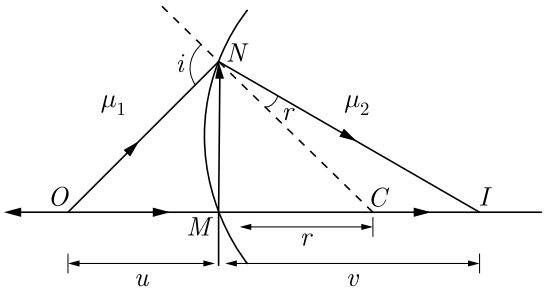
$$m = 1 - \frac{v}{f}$$

$$m = 1 + \frac{D}{f} \quad [v = -D]$$

194. Establish the formula $\frac{\infty_2}{v} - \frac{\infty_1}{v} = \frac{\infty_2 - \infty_1}{r}$

Ans : **SQP 2021, 2017**

A refracting surface which from a part of a sphere of transparent refracting material is called a spherical refracting surface.



In the figure, the geometry of formation of image I of an object O and the principal axis of a spherical surface with centre of curvature C and radius of curvature R.

Assumptions

1. The aperture of the surface is small as compared to other distances involved.
2. NM will be taken to be nearly equal to the length of the perpendicular from the point N on the principal axis.

$$\tan NOM = \frac{MN}{OM},$$

$$\tan NCM = \frac{MN}{MC},$$

$$\tan NIM = \frac{MN}{MI}$$

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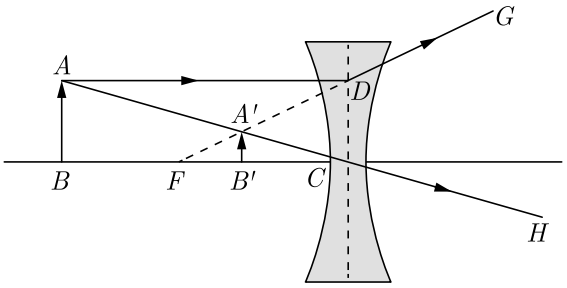
travels for long distances inside the optical fibre. This has been achieved by purification and special preparation of materials such as quartz.

187. Derive lens formula for a concave lens.

Ans : **SQP 2011**

Consider a concave lens of focal length f and optical centre C. Let an object AB be placed perpendicular to the principal axis at any suitable distance. The image formed by this lens is always virtual, erect and on the same side of the lens as shown in figure



ΔABC and $\Delta A'B'C$ are similar, so

$$\frac{A'B'}{AB} = \frac{CB'}{CB} \qquad ...(1)$$

ΔDCF and $\Delta A'B'F$ are similar, so

$$\frac{A'B'}{DC} = \frac{B'F}{CF}$$

But, $DC = AB$

Hence, $$\frac{A'B'}{AB} = \frac{B'F}{CF} \qquad ...(2)$$

From equations (1) and (2), we have

$$\frac{CB'}{CB} = \frac{B'F}{CF}$$

or $$\frac{CB'}{CB} = \frac{CF' - CB'}{CF} \qquad ...(3)$$

Using sign conventions,

Let $CB' = -v, CB = -u, CF = -f$

So equation (3) becomes,

$$\frac{-v}{-u} = \frac{-f+v}{-f}$$

or $$-vf = -uf + uv$$

Dividing both sides by uvf, we get

$$\frac{-vf}{uvf} = \frac{-uf}{uvf} + \frac{uv}{uvf}$$

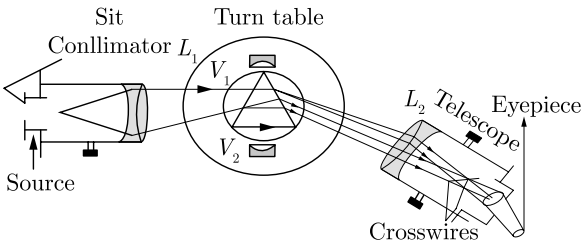
or $$-\frac{1}{u} = -\frac{1}{v} + \frac{1}{f}$$

or $$-\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

188. What is meant by pure and impure spectrum? Explain briefly how you will set up a spectrometer to obtain pure spectrum? Draw a diagram of a spectrometer and describe its parts.

Ans : **Main 2025**

Impure spectrum Spectrum is said to be impure in which there is a over lapping of different colours.



Pure spectrum Pure spectrum is one in which there is no over lapping of different colours take place.

Spectrometer It is an instrument used to study the spectra of luminous objects and also to find out the refractive index of any refracting material say, glass in the form of a prism.

The main parts of a spectrometer are

(i) **Collimator** It is a tube provided with a narrow slit S at one end and a converging lens at the other end. The narrow slit S is located at the focus of the lens.
When a source of light is placed in front of S.A.S parallel beam of light emerges from the collimator. These rays are incident on the refractive surface of a prism.

(ii) **Prism table** It has a flat circular top, capable of rotating about its vertical axis. The prism is placed on the table with its refracting edge parallel to the slit.

(iii) **Telescope** It is an astronomical telescope filled with an eyepiece and cross-wires. The spectrum is formed on the focal plane of the telescope and is viewed with an eyepiece having both of its lenses achromatic.
For the production of a pure spectrum, it is necessary that the slit should be very narrow and the incident beam of light should be parallel. Before using, the length of the telescopic tube is so adjusted that the image of the spectrum is well focussed. In this position, rays of different wavelengths (or colours) will be focussed at different points, thus producing a pure spectrum

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Also, $A = r + r' = r + r = 2r$

Hence, $r = \frac{A}{2}$

From Snell's law, the refractive index of the material of the prism will be.

$$\mu = \frac{\sin i}{\sin r} = \frac{\sin \frac{A+\delta_m}{2}}{\sin \frac{A}{2}}$$

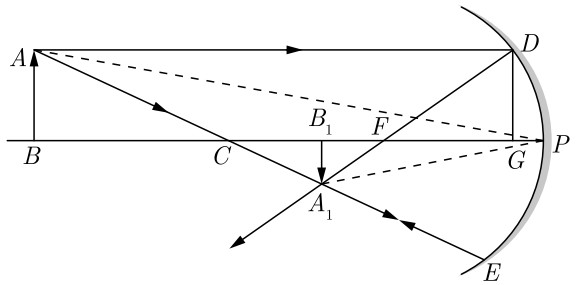
By measuring the value of A and δ_m, with the help of a spectrometer, the refractive index μ of the prism glass can be determined accurately.

196. What is meant by linear magnification of a spherical mirror? Derive expression for it.

Ans : **Main 2018**

Linear magnification or simply magnification of a spherical mirror is the ratio of the size of the image formed by the mirror to the size of the object.

It is represented by m,



This in figure.

$$m = \frac{\text{size of image } (I)}{\text{size of object } (O)} = \frac{A_1B_1}{AB}$$

Δs ΔABP and ΔA_1B_1P are similar.

$$\frac{A_1B_1}{AB} = \frac{PB_1}{PB}$$

In case of concave mirror, using new Cartesian sign conventions.

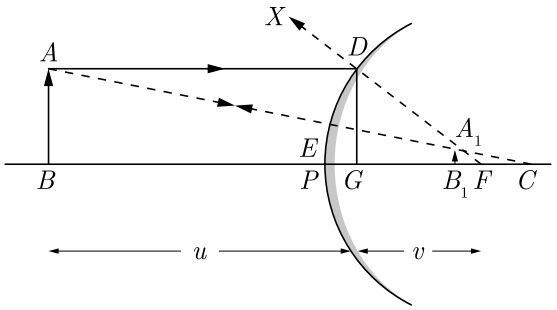
$$A_1B_1 = -I,\ AB = +O$$

$$PB_1 = -v,\ PB = -u$$

Hence, $\frac{-I}{O} = \frac{-v}{-u} = \frac{v}{u}$

Hence, $m = \frac{I}{O} = -\frac{v}{u}$

In case of a convex mirror, using new Cartesian sign conventions, [Figure].



$$A_1B_1 = +I,\ AB = +O$$

$$PB_1 = +v,\ PB = -u$$

Hence, $\frac{I}{O} = \frac{v}{-u}$

Hence, $m = \frac{I}{O} = -\frac{v}{u}$

When $m > 1$, image formed is enlarged.

When $m < 1$, image formed is diminished.

Again, when m is +ve, image must be erect (i.e. virtual)

When m is negative, image must be inverted (i.e. real)

Other formula for magnification.

From mirror formula,

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \quad ...(1)$$

Multiplying both side of equation (1) by v,

$$\frac{v}{u} + 1 = \frac{u}{f}$$

$$\frac{v}{u} = \frac{v}{f} - 1 = \frac{u-f}{f}$$

As, $m = -\frac{v}{u}$

Hence, $m = \frac{f-v}{f}$

Again, multiplying both sides of mirror formula in equation (1) by u,

$$1 + \frac{u}{v} = \frac{u}{f}$$

$$\frac{u}{v} = \frac{u}{f} - 1 = \frac{u-f}{f}$$

$$\frac{v}{u} = \frac{f}{u-f}$$

As, $m = -\frac{v}{u}$

$$m = \frac{f}{f-u}$$

Hence, $m = -\frac{v}{u} = \frac{f-v}{f} = \frac{f}{f-u}$

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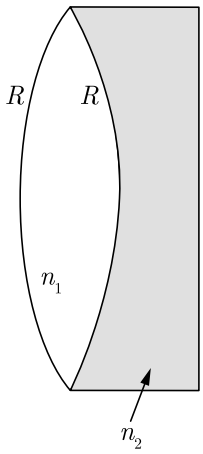
197. A biconvex lens with its two faces of equal radius of curvature R is made of a transparent medium of refractive index n_1. It is kept in contact with a medium of refractive index n_2 as shown in the figure.



(a) Find the equivalent focal length of the combination.

(b) Obtain the condition when this combination acts as diverging lens.

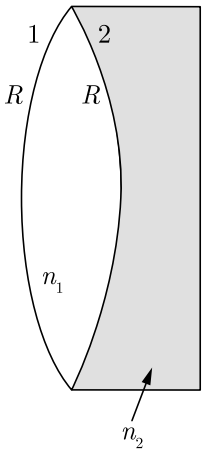
(c) Draw the ray diagram for the case $\mu_1 > \frac{(\mu_2+1)}{2}$. When the equal the object is kept far away from the lens. Point out the nature of the image formed by the system.

Ans : **Comp 2015, 2017**

(a) If refraction occurs at first surface,

$$\frac{n_1}{v_1} - \frac{1}{u} = \frac{n_1 - 1}{R} \qquad ...(1)$$

If refraction occurs at second surface, and the image of the first surface acts as an object



$$\frac{n_1}{v_1} - \frac{n_1}{v_1} = \frac{n_2 - n_1}{-R} \qquad ...(2)$$

On adding equation (1) and (2), we get

$$\frac{n_2}{v} - \frac{1}{u} = \frac{2n_1 - n_2 - 1}{R}$$

If rays are coming from infinity, i.e., $u = -\infty$ then $v = f$

$$\frac{n_2}{f} + \frac{1}{\infty} = \frac{2n_1 - n_2 - 1}{R}$$

$$f = \frac{n_2 R}{2n_1 - n_2 - 1}$$

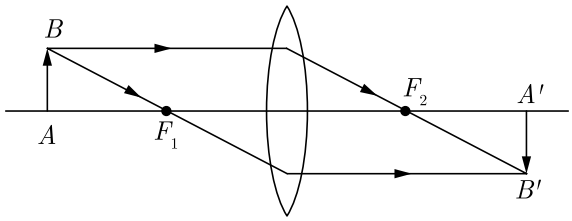
(b) If the combination behave as a diverging system then $f < 0$. This is possible only when,

$$2n_1 - n_2 - 1 < 0$$

$$2n_1 < n_2 + 1$$

$$n_1 < \frac{(n_2+1)}{2}$$

(c)



If the combination behaves as a converging lens then $f > 0$. It is possible only when,

$$2n_1 - n_2 - 1 > 0$$

$$2n_1 > n_2 + 1$$

$$n_1 > \frac{(n_2+1)}{2}$$

Nature of the image formed is real.

198. Describe the formation of real and virtual images by a convex lens with the help of diagrams at different positions of the object.

Ans : **SQP 2013, 2011**

Let us discuss following cases :

1. **When Object is Placed between Optical Centre and the Principal Focus of the Convex Lens :** The incident ray AD which is parallel to t he principal axis, passes through the principal focus F after refraction and ray AH which is passing through the optical centre goes undeviated. These two rays when produced in backward direction, meet at A', so $A'B'$ is the virtual image of real object AB Figure (a).

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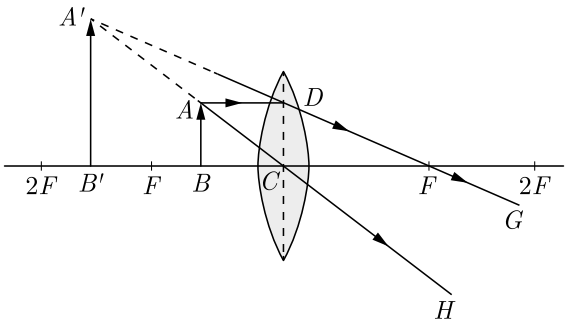
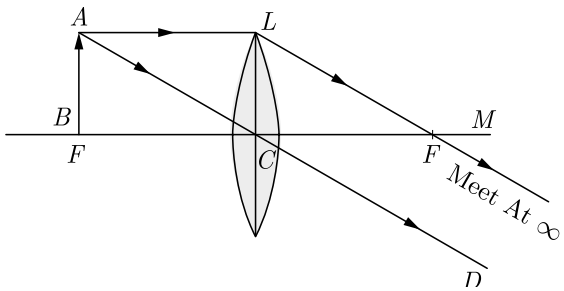


(a)

Here the image is virtual, erect, magnified and is formed behind the object.

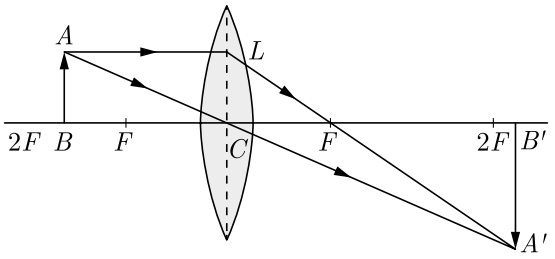
2. **When Object is Placed at the Principal Focus of the Convex Lens :** The incident ray AL which is parallel to the principal axis, passes through the focus F after refraction and ray AD, which passes through the optical centre C, goes undeviated. These two rays are parallel and they meet at infinity. Thus real image of object AB is formed at infinity. Figure (b).



(b)

Here the image is real, inverted, highly enlarged and is formed at infinity.

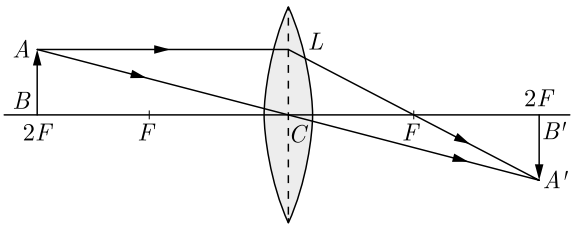
3. **When Object is Placed between F and 2F :** The incident ray AL, which is parallel to the principal axis, passes through the focus F after refraction and ray AA', which passes through the optical centre C, goes undeviated. These two rays meet at point A'. So $A'B'$ is the real image of object AB.



(c)

Here the image is real, inverted, magnified and is formed beyond $2F$. Figure (c)

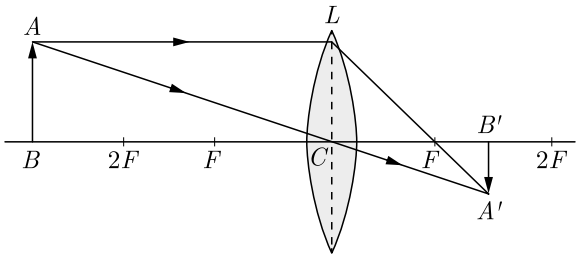
4. **When Object is Placed at $2F$:** The incident ray AL, which is parallel to the principal axis, passes through the focus F after refraction and ray AA', which passes through the optical centre C goes undeviated. These two rays meet at point A'. So $A'B'$ is the real image of object AB Figure (d).



(d)

Here the image is real, inverted, equal to the size of object and is formed at $2F$ on other side of the lens.

5. **When the Object is Placed beyond $2F$:** The incident ray AL, which is parallel tot he principal axis, passes through the principal focus F after refraction, and the ray AA' which passes through the optical centre C goes undeviating. These two rays meet at point A'. So $A'B'$ is the real image of object AB. Figure (e).



(e)

Here, the image is real, inverted, smaller in size and is formed between F and $2F$ on the other side of the lens.

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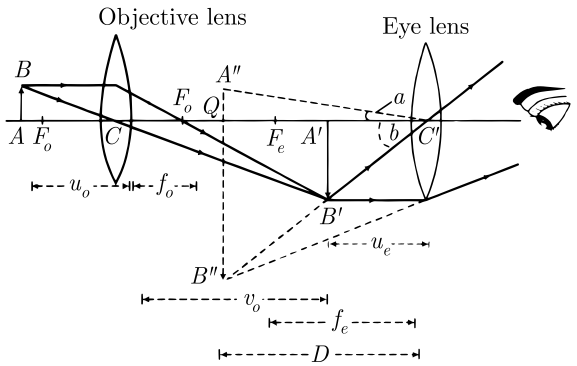
The first inverted image is thus near the focal plane of the eyepiece, at a distance appropriate for final image formation at infinity or a little closer for image formation at the near point. The final image is inverted with respect to the original object.



Angular magnification or magnifying power of compound microscope is defined as the ratio of the angle β subtended by the final image at the eye to the angle α subtended by the object seen directly, when both are placed at least distance of distinct vision.

Hence, Angular magnification,

$$m = \frac{\beta}{\alpha}$$

Since, the angles are small, then

$$\alpha \approx \tan\alpha \text{ or } \beta \approx \tan\beta$$

Hence, $$m = \frac{\tan\beta}{\tan\alpha} \quad ...(1)$$

From right angles $\Delta\, C'QB''$, we have

$$\tan\beta = \frac{B''Q}{C'Q} = \frac{B''Q}{D} = \frac{A''B''}{D}$$

Also, from right angled $\Delta\, C'A''Q$, we have

$$\tan\alpha = \frac{A''Q}{C'Q}$$

$$= \frac{AB}{D} \quad [\text{Since, } A''Q = AB]$$

Substituting the values of tan α and $\tan\beta$ in equation (1), we have

$$m = \frac{B''Q}{D} \times \frac{D}{AB} = \frac{B''Q}{AB}$$

$$= \frac{B''Q}{A'B'} \times \frac{A'B'}{AB}$$

Thus, the magnification produced by the compound microscope is the product of the magnification produced by the eyepiece and objective.

Hence, $$m = m_e \times m_o \quad ...(2)$$

Where, m_e and m_o are the magnifying powers of the eyepiece and objective, respectively.

The linear magnification of the real inverted image produced by the eyepiece is $\frac{A''B''}{A'B'}$.

Case I When the Final Image is Formed at Near Point

Linear magnification is given by,

$$m_e = 1 + \frac{D}{f_e} \quad ...(3)$$

where, f_e is local length of the eyepiece.

$\frac{A'B'}{AB}$ is the linear magnification of the object produced by the objective.

$$m_0 = \frac{v_0}{u_0} \quad ...(4)$$

From equation. (2), (3) and (4), we have

$$m = \frac{v_0}{u_0}\left(1 + \frac{D}{f_e}\right) \quad ...(5)$$

$$\frac{1}{v_0} - \frac{1}{u_0} = \frac{1}{f_0}$$

Multiplying both sides by v_0, we have

$$\frac{v_0}{v_0} - \frac{v_0}{u_0} = \frac{v_0}{f_0}$$

$$\frac{-v_0}{u_0} = -1 + \frac{v_0}{f_0}$$

$$\frac{v_0}{u_0} = 1 - \frac{v_0}{f_0}$$

Substituting the value of $\frac{v_0}{u_0}$ in equation (5), we have

$$m = \left(1 - \frac{v_0}{f_0}\right)\left(1 + \frac{D}{f_e}\right)$$

Case II When the Final Image is at Infinity

If u_0 is the distance of the object from the objective and v_0 is the distance of the image from the objective, then the magnifying power of the objective is,

$$m_0 = \frac{v_0}{u_0}$$

When the final image is at infinity, then angular magnification is given by,

$$m_e = \frac{D}{f_e}$$

The total magnification when image is at infinity is given by,

$$m = m_e \times m_e = \left(\frac{v_0}{u_0} \times \frac{D}{f_e}\right)$$

If the object is very close to the principal focus of the objective and the image formed by the objective is very close to the eyepiece then

$$m = \frac{-L}{f_0} \cdot \frac{D}{f_e}$$

where, L = Length of the tube of microscope in this case the microscope is said to be in normal adjustment.

NODIA

From Snell's law for small i_1 and r_1, we have

$$\frac{\sin i_1}{\sin r_2} = \frac{i_1}{r_1} = \frac{\alpha_2}{\alpha_1}$$

$$\mu_1 i_1 = \mu_2 r_1 \quad ...(1)$$

In ΔAOC_1, $\gamma_1 = i_1 + \alpha_1$

$$i_1 = \gamma_1 - \alpha_1$$

In ΔAI_1C_1, $\gamma_1 = \beta_1 + r_1$

$$r_1 = \gamma_1 - \beta_1$$

Putting the values of i_1 and r_1 in equation (1), we get

$$\mu_1(\gamma_1 - \alpha_1) = \mu_2(\gamma_1 - \beta_1)$$

$$\mu_1\gamma_1 - \mu_1\alpha_1 = \mu_2\gamma_1 - \mu_2\beta_1$$

$$-\mu_1\alpha_1 + \mu_2\beta_1 = (\mu_2 - \mu_1)\gamma_1$$

Since, α_1, β_1 and γ_1 are small, so they can be replaced by their tangents.

So, $-\mu_1\tan\alpha_1 + \mu_2\tan\beta_1 = (\mu_2 - \mu_1)\tan\gamma_1$

$$-\alpha_1\frac{AM_1}{M_1O} + \alpha_2\frac{AM_1}{M_1I_1} = (\alpha_2 - \alpha_1)\frac{AM_1}{M_1C_1}$$

$$-\frac{\alpha_1}{M_1O} + \frac{\alpha_2}{M_1I_1} = \frac{(\alpha_2 - \alpha_1)}{M_1C_1}$$

Since point M_1 is very close to C. So,

$$M_1O = CO,\ M_1I_1 = CI_1$$

and $M_1C_1 = CC_1$

Hence, $$-\frac{\alpha_1}{CO} + \frac{\alpha_2}{CI_1} = \frac{\alpha_2 - \alpha_1}{CC_1} \quad ...(2)$$

Refraction at X_2Y_2

Actually the lens material is not continuous and the ray AB suffers refraction at B and bend away from the normal along BQ. When BQ is produced in backward direction, it meets ate I on the principal axis and I is the virtual image of virtual object I_1.

From Snell's law for small i_2 and r_2, we have

$$\frac{\sin i_2}{\sin r_2} = \frac{i_2}{r_2} = \frac{\alpha_1}{\alpha_2}$$

or $$\alpha_1\alpha_2 = \mu_2 i_2 \quad ...(3)$$

In ΔBC_2I_1 $i_2 = \beta_1 + \gamma_2$

In ΔBC_2I

Putting the value of i_2 and r_2 in equation (3), we get

$$\mu_1(\beta_2 + \gamma_2) = \mu_2(\beta_1 + \gamma_2)$$

or $$\mu_1\beta_2 + \mu_1\gamma_2 = \mu_2\beta_1 + \mu_2\gamma_2$$

or $$\mu_1\beta_2 - \mu_2\beta_1 = (\mu_2 - \mu_1)\gamma_2$$

Since, β_2, β_1 and γ_2 are small, so they can be replaced by their tangents. So,

$$\mu_1\tan\beta_2 - \mu_2\tan\beta_1 = (\mu_2 - \mu_1)\tan\gamma_2$$

$$\alpha_1\frac{BM_2}{M_2I} - \alpha_2\frac{BM_2}{M_2I_1} = (\alpha_2 - \alpha_1)\frac{BM_2}{M_2C_2}$$

$$\frac{\alpha_1}{M_2I} - \frac{\alpha_2}{M_2I_1} = \frac{\alpha_2 - \alpha_1}{M_2C_2}$$

Since, point M_2 is every close to C, so

$$\frac{\alpha_1}{CI} - \frac{\alpha_2}{CI_1} = \frac{\alpha_2 - \alpha_1}{CC_2} \quad ...(4)$$

Adding equations (2) and (4), we get

$$-\frac{\alpha_1}{CO} + \frac{\alpha_1}{CI} = (\alpha_2 - \alpha_1)\left[\frac{1}{CC_1} + \frac{1}{CC_2}\right]$$

Using sign conventions,

$$CO = -u,\ CI = v$$

$$CC_1 = -R \text{ and } CC_2 = -R_2$$

$$\frac{-\alpha_1}{-u} + \frac{\alpha_1}{-v} = (\alpha_2 - \alpha_1)\left(\frac{1}{-R_1} + \frac{1}{R_2}\right)$$

$$\frac{-\alpha_1}{u} + \frac{\alpha_1}{v} = (\alpha_2 - \alpha_1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Dividing both sides by μ_1, we get

$$-\frac{1}{u} + \frac{1}{v} = \left(\frac{\alpha_2}{\alpha_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Writing, $\frac{\alpha_2}{\alpha_1} = \mu$, we get

$$-\frac{1}{u} + \frac{1}{v} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Since, $-\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$

Where, f = focal length of the lens

So, $$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

This is required lens maker's formula for this concave lens.

201. Explain with a neat diagram, the working of a compound microscope. Obtain an expression for its magnifying power.

Ans : **Main 2020, 2009**

Compound Microscope

A compound microscope consists of two convex lenses coaxially separated by some distance. The lens nearer to the object is called the objective. The lens through which the final image is viewed is called the eyepiece.

Working

The objective of compound microscope forms the real, inverted and magnified image of the object. This image serves as the object for the second lens, i.e., eyepiece which produces the final image, which is enlarged and virtual.

NODIA

224. A convex lens of focal length $f = 20$ cm is combined with a diverging lens of power 6.5 D. What are the power and focal length of the combination?

Ans : **Main 2024**

Focal length

$$f = 20\,\text{cm} = 20 \times 10^{-2}\,\text{m}$$

and Power $P_2 = 6.5\,\text{D}$

We know power, $P_1 = \frac{1}{f_1} = \frac{1}{20 \times 10^{-2}} = 5\,\text{D}$

Power of the combination

$$P_{\text{equivalent}} = P_1 + P_2$$
$$= 5 + 6.5 = 11.5\,\text{D}$$

Focal length of the combination

$$f_{\text{eq}} = \frac{1}{P} = \frac{1}{11.5} = 8.7\,\text{cm}$$

225. An astronomical telescope is adjusted to form the final image at infinity. The separation between the lenses is 80 cm. The angular magnification is 15. Calculate the focal lengths of the objective lens and the eyepiece.

Ans : **Main 2007, 2005**

Let f_o and f_e are the focal lengths of the objective and the eyepiece respectively. When final image is at infinity,

Given, $L = f_o + f_e = 80\,\text{cm},\ M = 15,\ M = \frac{f_o}{f_e}$

$$f_o = 15 f_e,\ L = f_o + f_e \quad \ldots(1)$$

Putting the values of f_o and L in Eq. (1), we get

$$80 = 15 f_e + f_e,\ f_e = 5\,\text{cm}$$

So, $f_o = 15 f_e = 15 \times 5,\ f_o = 75\,\text{cm}$

226. The radii of curvature of both the surfaces of a lens are equal. If one of the surfaces is made plane by grinding then will the focal length of lens change? Will the power change?

Ans : **Comp 2015**

Focal length of lens,

$$\frac{1}{f} = (n-1)\left(\frac{1}{R} + \frac{1}{R}\right)$$
$$f = \frac{R}{2(n-1)}$$

When one surface is made plane,

$$\frac{1}{f} = (n-1)\left(\frac{1}{R} + \frac{1}{\infty}\right)$$

Hence, $f' = \frac{R}{(n-1)} = 2f$

That is, the focal length will be doubled.

As $P = \frac{1}{f}$, so power will be halved.

227. A ray of light of frequency 5×10^{14} Hz is passed through a liquid. The wavelength of light measured inside the liquid is found to be 450×10^{-9} m. Calculate the refractive index of the liquid.

Ans : **Comp 2018**

Given, $\nu = 5 \times 10^{14}\,\text{Hz}$

$$\lambda = 450 \times 10^{-9}\,\text{m}$$
$$c = 3 \times 10^{8}\,\text{ms}^{-1}$$

Refractive index of the liquid,

$$\mu = \frac{c}{v} = \frac{c}{\nu\lambda}$$
$$= \frac{3 \times 10^{8}}{5 \times 10^{14} \times 450 \times 10^{-9}} = 1.33$$

228. An astronomical telescope consists of two thin convex lenses having focal lengths of 140 cm and 5 cm. The telescope is adjusted to be in normal adjustment.

(i) What is the angular magnification, i.e. magnifying power of the telescope in this set up?

(ii) What is the distance between the two lenses equal to?

Ans : **Main 2011**

According to the question,

Given, $f_o = 140\,\text{cm},\ f_e = 5\,\text{cm}$

(i) Angular magnification,

$$M = \frac{-f_o}{f_e} = \frac{-140}{5} = -28$$

(ii) Distance between the lenses

$$L = f_o + f_e = 140 + 5 = 145\,\text{cm}$$

229. For a glass prism ($\mu = \sqrt{3}$) the angle of minimum deviation is equal to the angle of the prism. Calculate the angle of the prism.

Ans : **SQP 2013**

At minimum deviation,

$$\mu = \frac{\sin\left[\frac{(A+\delta_m)}{2}\right]}{\sin\left(\frac{A}{2}\right)}$$

Given, $\delta_m = A$

Hence, $\mu = \frac{\sin A}{\sin\frac{A}{2}} = \frac{2\sin\frac{A}{2}\cos\frac{A}{2}}{\sin\frac{A}{2}}$

$$= 2\cos\frac{A}{2}$$
$$\cos\frac{A}{2} = \frac{\sqrt{3}}{2}$$
$$\frac{A}{2} = 30$$
$$A = 60^\circ$$

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NUMERICAL QUESTIONS

202. Find the focal length and nature of a lens whose optical power is – 5 D.

Ans : Main 2013

According to the question, Power of a lens $= -5$ D

$$\text{Focal length (metre)} = \frac{1}{\text{Power of lens}}$$

$$= \frac{1}{-5/100} = -20 \text{ cm}$$

Since, focal length of lens is negative so, it is concave lens.

203. Calculate the critical angle for glass and water pair. (Take, refractive index for glass is 1.50 and the refractive index for water is 1.33.)

Ans : Main 2010

Given, refractive index of glass $\mu_g = 1.50$

Refractive index of water $\mu_w = 1.33$

Let C be critical angle, then from Snell's law

$$\sin C = \frac{1}{{}_w\alpha_g} = \frac{\alpha_w}{\alpha_g} = \frac{1.33}{1.50}$$

$$C = \sin^{-1}\left(\frac{1.33}{1.50}\right) = 62.5^\circ$$

204. How does focal length of a convex lens change with increase in wavelength of incident light?

Ans : Main 2014, 2010

Refractive index (μ) varies inversely with the wavelength (λ) of light used and for convex lens focal length (f) is given by

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

where, R_1 and R_2 are radius of curvature of two surfaces. So, on increasing wavelength, refractive index decreases and focal length increases.

205. A converging lens of focal length 40 cm is kept in contact with a diverging lens of focal length 30 cm. Find the focal length of the combination

Ans : SQP 2007

The focal length of the combination will be

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} = \frac{1}{40} + \frac{1}{-30}$$

$$= \frac{1}{40} - \frac{1}{30} = \frac{3-4}{120} = -\frac{1}{120}$$

$$f = -120 \text{ cm} = -\frac{120}{100} = -1.2 \text{ m}$$

206. Find the value of critical angle for a material of refractive index $\sqrt{3}$.

Ans : Main 2014

Given, $\mu = \sqrt{3}$

$$\sin i_c = \frac{1}{\mu} = \frac{1}{\sqrt{3}}$$

$$= \frac{\sqrt{3}}{3} = 0.5773$$

Hence, critical angle, $i_c \simeq 35.3^\circ$

207. Calculate the speed of light in a medium, whose critical angle is 45°.

Ans : Main 2017

Given, $i_c = 45^\circ$

As we know that, $\mu = \frac{c}{v} = \frac{1}{\sin i_c}$

Hence, $v = c \sin i_c = 3 \times 10^8 \times \sin 45^\circ$

$$= 3 \times 10^8 \times 0.707$$

$$= 2.121 \times 10^8 \text{ ms}^{-1}$$

208. The velocity of light in a liquid is $1.5 \times 10^8 \text{ ms}^{-1}$ and in air, it is $3 \times 10^8 \text{ ms}^{-1}$. If a ray of light passes from this liquid into air, calculate the value of critical angle.

Ans : SQP 2012, 2011

Given, $v = 1.5 \times 10^8 \text{ ms}^{-1}$

$c = 3 \times 10^8 \text{ ms}^{-1}$

Refractive index of the liquid,

$$\mu = \frac{c}{v} = \frac{3 \times 10^8}{1.5 \times 10^8} = 2$$

or $\sin i_c = \frac{1}{\mu} = \frac{1}{2}$

Hence, Critical angle, $i_c = 30^\circ$

209. A biconvex lens made of glass (refractive index 1.5) has two spherical surfaces having radii 20 cm and 30 cm. Calculate its focal length.

Ans : Main 2025

Given, $R_1 = 20$ cm and $R_2 = -30$ cm

and $n = 1.5$

The focal length of a lens is given by

$$\frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

$$= (1.5-1)\left[\frac{1}{20} + \frac{1}{30}\right] = (0.5)\left[\frac{5}{60}\right]$$

$$f = \frac{600}{25} = 24 \text{ cm}$$

NODIA

Angle of deviation produced by the small-angled prism,

$$\delta = (\mu - 1)\, A$$

Angle of prism, $$A = \frac{\delta}{\mu - 1}$$

$$= \frac{4.9^\circ}{1.7 - 1} = \frac{4.9^\circ}{0.7} = 7^\circ$$

236. The radius of curvature of each face of biconcave lens, made of glass of refractive index 1.5 is 30 cm. Calculate the focal length of the lens in air.

Ans : **Main 2007**

Given, $\mu = 1.5$

$R_1 = -30$ cm

$R_2 = +30$ cm

Using lens maker's formula,

$$\frac{1}{f} = (\mu - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

$$= (1.5 - 1)\left[\frac{1}{-30} - \frac{1}{30}\right]$$

$$= -0.5 \times \frac{2}{30} = -\frac{1}{30}$$

Hence, $f = -30$ cm

237. Find critical angle for glass and water pair, given refractive index of glass is 1.62 and that of water is 1.33.

Ans : **Main 2016, 2014**

Given,

Refractive index of glass is $\mu_g = 1.62$

Refractive index of water is, $\mu_w = 1.33$

From Snell's law of refraction,

$$^a\mu_g = \frac{\sin i}{\sin r} = \frac{\alpha_w}{\alpha_g}$$

For the critical for glass-water pair, $r = 90^\circ$

$$\frac{\sin i_C}{\sin 90^\circ} = \frac{1.33}{1.62}$$

$$\sin i_C = 0.820$$

$$i_C = \sin^{-1}(0.820) = 55.08^\circ$$

238. A ray of light suffers minimum deviation when incident on a prism of refractive index $\sqrt{2}$. What is the angle of incidence?

Ans : **Main 2025**

Refractive index of prism,

$$\mu = \sqrt{2}$$

refractive index of prism,

$$\mu = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

$$\sin\left(\frac{A + \delta_m}{2}\right) = \mu \sin\left(\frac{A}{2}\right) = \sqrt{2}\sin\left(\frac{60^\circ}{2}\right)$$

$$= \sqrt{2}\sin 30^\circ = \sqrt{2} \times \frac{1}{2} = \frac{1}{\sqrt{2}}$$

$$\frac{A + \delta_m}{2} = \sin^{-1}\left(\frac{1}{\sqrt{2}}\right) = 45^\circ$$

We also know that angle of incidence,

$$i = \frac{A + \delta_m}{2} = 45^\circ$$

239. A glass prism ($\mu_g = 1.66$) of angles of Prism 72°, is placed in water ($\mu_w = 1.33$). Calculate the value of minimum deviation produced by prism for parallel incident ray.

Ans : **Main 2011**

Angle of deviation,

$$\delta_m = \left(\frac{n_2}{n_1} - 1\right)A$$

Here, $n_1 = 1.33$

$n_2 = 1.66$

Angle of prism, $A = 72$

Hence, $$\delta_m = \left(\frac{1.66}{1.33} - 1\right)72$$

$$= (1.24 - 1) \times 72$$

$$= 0.24 \times 72 = 17.8^\circ$$

240. Green light of wavelength 5460 Å is incident on an air and glass interface. If refractive index of glass is 1.5, What is the wavelength of light in glass?

Ans : **SQP 2011**

Actual wavelength of light,

$$\lambda = 5460\ \text{Å}$$

and refractive index of glass,

$$\mu = 1.5$$

We know that ,wavelength of light in glass,

$$\lambda = \frac{\lambda}{\mu} = \frac{5460}{1.5} = 3640\ \text{Å}$$

241. A convex lens of a focal length 5 cm is used as a simple microscope. Where should an object be placed so that the image formed by it lies at the least distance of distinct vision ($D = 25$ cm)?

Ans : **Main 2015**

According to the question,

focal length of convex lens $(f) = 5$ cm

i.e. $f = +5$ cm

Image distance $v = -D = -25$ cm

Now, from thin lens formula,

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217. The sun glasses have curved surfaces, but their power zero Why?

Ans : **Main 2005, 2001**

The sunglasses have curved surfaces, the curved surface have the radii of curvature equal.

Since, $R_1 = R_2 = R$

$$P = \frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

where, $P =$ power of lens.

$$P = \frac{1}{f} = (n-1)\left(\frac{1}{R} - \frac{1}{R}\right) = 0$$

218. A converging lens is kept coaxially in contact with a diverging lens both the lenses being of equal focal length. What is the focal length of the combination?

Ans : **Comp 2010**

Let focal length of the combination be f.

Hence,
$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$$
$$\frac{1}{f} = \frac{1}{f} + \left(-\frac{1}{f}\right)$$
$$\frac{1}{f} = 0$$
$$f = \frac{1}{0} = \text{infinity}$$

219. When observed from under water, all the objects above the surface can be seen within a cone of 97° Why ? Explain

Ans : **Comp 2011**

Since the critical angle C and refractive index μ is given by

$$\sin C = \frac{1}{\mu}$$

For water, $\mu = 1.33$

$$\sin C = \frac{1}{1.33} = 0.7519$$

or $C = 48.75^\circ$

Angle of the cone $= 48.75^\circ \times 2 = 97^\circ$

220. If a thin prism of 6° gives a deviation of 3°, what is the refractive index of the prism material?

Ans : **SQP 2016**

Angle of prism, $A = 6^\circ$

Angle of devotion, $\delta = 3^\circ$

angle of deviation produced by small-angled prism,

$$\delta = (\mu - 1)A$$
$$\mu - 1 = \frac{\delta}{A} = \frac{3^\circ}{6^\circ} = 0.5$$
$$\mu = 0.5 + 1 = 1.5$$

where, μ = refractive index of the prism material

221. A thin convex lens of focal length 20 cm is kept in contact with a thin concave lens of focal length 15 cm. Find the focal length and the nature of the combination.

Ans : **SQP 2018**

Let f_1 and $-f_2$ be the focal lengths of convex lens and concave lens, respectively. Then total focal length of the combination is

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{(-f_2)}$$

Here, $f_1 = 20\text{ cm}$

$f_2 = -15\text{ cm}$

$$\frac{1}{f} = \frac{1}{20} - \frac{1}{15} = \frac{3-4}{60} = -\frac{1}{60}$$

Total focal length, $f = -60\text{ cm}$

222. A biconvex lens made of glass (refractive index 1.5) has two spherical surfaces having radii 10 cm and 20 cm. Calculate its focal length.

Ans : **Main 2022 Sem-II**

Given, $\mu = 1.5$

$R_1 = 10\text{ cm}$, $R_2 = -20\text{ cm}$

Using lens Maker's formula

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$
$$= (1.5 - 1)\left(\frac{1}{10} + \frac{1}{20}\right)$$
$$= 0.5 \times \left(\frac{2+1}{20}\right) = 0.5 \times \frac{3}{20} = \frac{3}{40}$$
$$f = \frac{40}{3} = 13.3\text{ cm}$$

223. The power of two lenses are +12 D and –2 D. They are placed in contact on the same axes. What will be the focal length of the combination?

Ans : **SQP 2012**

Power of first lens, $P_1 = +12\text{ D}$

Power of second lens, $P_2 = -2\text{ D}$

Now, Power of equivalent lens,

$$P = P_1 + P_2$$
$$= 12\text{ D} - 2\text{ D} = 10\text{ D}$$

Focal length, $f = \frac{1}{P} = \frac{1}{10}$ meter

$$= \frac{1}{10} \times 100 = 10\text{ cm}$$

NODIA

210. Calculate refractive index of the material of an equilateral prism if its angle of minimum deviation is 30°.

Ans : **Main 2022 Sem-II**

Given, $\delta_m = 30^\circ$

For equilateral prism, $A = 60^\circ$

Refractive index, $\mu = \dfrac{\sin\left(\frac{\delta_m + A}{2}\right)}{\sin\frac{A}{2}}$

$$= \frac{\sin\left(\frac{30^\circ + 60^\circ}{2}\right)}{\sin\left(\frac{60^\circ}{2}\right)}$$

$$= \frac{\sin 45^\circ}{\sin 30^\circ} = \sqrt{2} = 1.414$$

211. A thin converging lens of focal length 15 cm is kept in contact with a thin diverging lens of focal length 20 cm. Find the focal length of this combination.

Ans : **Main 2009, 2000**

Given,

Focal length of converging lens $f_1 = 15$ cm

Focal length of diverging lens $f_2 = -20$ cm

Since, $\dfrac{1}{f_{\text{equivalent}}} = \dfrac{1}{f_1} + \dfrac{1}{f_2}$

$$\frac{1}{f_{\text{equivalent}}} = \frac{1}{15} + \left(-\frac{1}{20}\right) = \frac{4-3}{60} = \frac{1}{60}$$

$$f_{\text{equivalent}} = 60 \text{ cm}$$

212. An astronomical telescope set for normal adjustment has a magnifying power 10. If the focal length of the objective is 1.20 m, what is the focal length of the eyepiece ?

Ans : **Main 2001**

The magnitude of the magnifying power of the astronomical telescope is given by, $|M| = \dfrac{f_o}{f_e}$

Where, f_o, is the focal length of objective and f_e is the focal length of eyepiece.

$$10 = \frac{1.20}{f_e}$$

$$f_e = \frac{1.20}{10} = 0.12 \text{ m} = 12 \text{ cm}$$

Thus, the eyepiece of the telescope will be of focal length 12 cm.

213. An astronomical telescope uses two lenses of powers 10 D and 1 D. If the final image of a distant object is formed at infinity, calculate the length of the telescope.

Ans : **Main 2014**

As we know that,

Power, $P = \dfrac{100}{f\,(\text{in cm})}$

$$f = \frac{100}{P}$$

$$f_1 = \frac{100}{10} = 10 \text{ cm}$$

Length of telescope $= f_1 + f_2 = 110$ cm

214. An astronomical telescope consists of two convex lenses having focal lengths 80 cm and 4 cm. When it is in normal adjustment, what is its

(i) length?

(ii) magnifying power?

Ans : **Main 2009**

Given, $f_o = 80$ cm, $f_e = 4$ cm

(i) Length of the telescope

$$= f_o + f_e = 84 \text{ cm}$$

(ii) Magnifying power,

$$M = \frac{-f_o}{f_e} = \frac{-80}{4} = -20$$

215. What is the angle of refraction made by a ray of light inside a regular i.e. an equilateral glass prism in the minimum deviation?

Ans : **Main 2007**

When refraction takes place through a prism

$$\angle A = r_1 + r_2$$

$\angle A =$ Angle of prism, $\angle r_1$ and $\angle r_2$ are refracting angle.

For minimum deviation,

$$r_1 = r_2 = r$$

$$\angle A = 2r$$

$$60^\circ = 2r$$

$$r = 30^\circ$$

216. The angle of an equilateral glass prism is 59.5°. The angle of minimum deviation is 38.5°. Without using the value of refractive index of the glass. Calculate the angle of incidence for a ray of light suffering minimum deviation.

Ans : **Main 2007**

As we know for the case of minimum deviation,

$$i = \frac{A + \delta_{\min}}{2}$$

where, $\delta_{\min}$ = minimum deviation angle,

i = angle of incidence

Given, $\angle A = 59.5^\circ$, $\delta_{\min} = 38.5^\circ$

$$i = \frac{59.5 + 38.5}{2} = 49^\circ$$

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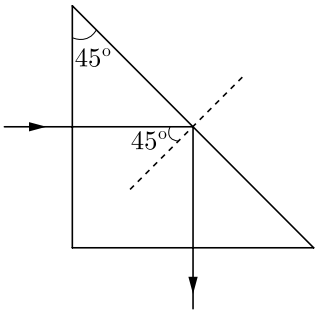
230. Draw ray diagram when incident ray normally on one of the two equal sides of a right angled isosceles prism having refractive index $\mu = \sqrt{3}$.

Ans : SQP 2013

$$\mu = \sqrt{3} = \frac{1}{\sin i_c}$$

$$\sin i_c = \frac{1}{\sqrt{3}}$$



231. A thin converging lens of focal length 12 cm is kept in contact with a thin diverging lens of focal length 18 cm. Calculate the effective/equivalent focal length of the combination.

Ans : Main 2022 Sem-II

Focal length of converging lens is positive.

$$f_1 = +12\,\text{cm}$$

Focal length of diverging lens is negative.

$$f_2 = -18\,\text{cm}$$

Equivalent focal length of the combination is given by

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$$

$$\frac{1}{f} = \frac{1}{12} - \frac{1}{18}$$

$$\frac{1}{f} = \frac{1}{36}$$

$$f = 36\,\text{cm}$$

232. Where should an object be kept on the principal axis of a convex lens of focal length 20 cm in order to get an image, which is double of the size of the object?

Ans : Main 2011

Given, focal length $f = 20\,\text{cm}$,

Magnification, $m = 2$

magnification $m = v/u$

So, $2 = \frac{v}{u}$

or $v = 2u$

We know that, $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$ [For convex lens]

where, symbols have their usual meaning.

$$\frac{1}{2u} + \frac{1}{u} = \frac{1}{20}$$

$$u = 30\,\text{cm}$$

233. What are the two possible values of the magnifying powers of a simple microscope made of convex lens of focal length $f = 5.0$ cm.

Ans : Main 2003

Case I When image is formed at near point.

Magnifying power of lens will be

$$M = 1 + \frac{D}{f}$$

It depends upon the focal length. For normal eye, the least distance of distinct vision,

$$D = 25\text{cm}$$

$$M = 1 + \frac{25}{5} = 6$$

Case II When image is formed at infinity.

Magnifying power,

$$M = \frac{D}{f} = \frac{25}{5} = 5$$

234. The refractive index of glass is 1.5 and that of water is 1.3. If the speed of light in water is $2.25 \times 10^8\,\text{ms}^{-1}$, what is the speed of light is glass?

Ans : SQP 2013

As we know that,

$$^a\mu_g = \frac{c}{v_g} = 1.5$$

and $$^a\mu_w = \frac{c}{v_\omega} = 1.3$$

Hence, $$\frac{c}{v_\omega} \times \frac{v_g}{c} = \frac{1.3}{1.5}$$

or $$v_g = \frac{1.3}{1.5} \times v_\omega$$

$$= \frac{1.3}{1.5} \times 2.25 \times 10^8$$

$$= 1.95 \times 10^8\,\text{ms}^{-1}$$

235. A small-angled prism of refractive index 1.7 gives a deviation of 4.9°. What is the angle of prism?

Ans : Main 2007

Refractive index of prism,

$$\mu = 1.7$$

and angle of deviation,

$$\delta = 4.9^\circ$$

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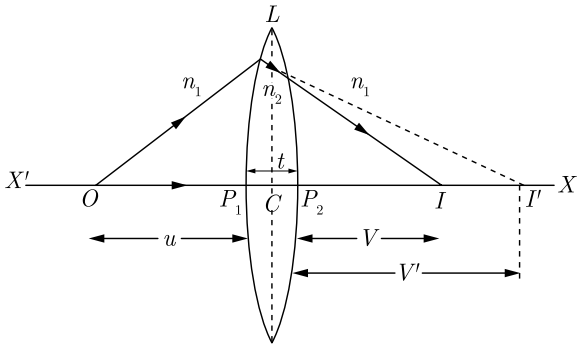
199. Draw a ray diagram for formation of image of a point object by a thin double convex lens having radii of curvature R_1 and R_2. Hence, derive lens maker's formula for a double convex lens. State the assumptions made and sign convention used.



Ans : **Main 2013, 2015**

Suppose L is a thin lens. The refractive index of the material of lens is n_2 and it is placed in a medium of refractive index n_1. The optical centre of lens is C and X' X is principal axis. The radii of curvature of the surfaces of the lens are R_1 and R_2 and their poles are P_1 and P_2. The thickness of lens is t, which is very small. O from pole P_1 is u. The first refracting surface forms the image of O at I' at distance v' from P_1. From the refraction formula at spherical surface,

$$\frac{n_2}{v'} - \frac{n_1}{u} = \frac{n_2 - n_1}{R_1} \qquad ...(1)$$

The image I' acts as a virtual object for second surface and after refraction at second surface, the final image is formed at I. The distance of I from pole P_2 of second surface is v. The distance of virtual object (I') from pole P_2 is $(v' - t)$.

For refraction at second surface, the ray a going from second medium (refractive index n_2) to first medium (refractive index n_1), therefore, from refraction formula at spherical surface,

$$\frac{n_1}{v} - \frac{n_2}{(v' - t)} = \frac{n_1 - n_2}{R_2} \qquad ...(2)$$

For a thin lens t is negligible as compared to v', therefore from eq. (2)

$$\frac{n_1}{v} - \frac{n_2}{v'} = -\frac{n_2 - n_1}{R_2} \qquad ...(3)$$

Adding equations (1) and (3), we get

$$\frac{n_1}{v} - \frac{n_1}{u} = (n_2 - n_1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\frac{1}{v} - \frac{1}{u} = \left(\frac{n_2}{n_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

i.e., $$\frac{1}{v} - \frac{1}{u} = ({}_1n_2 - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \qquad ...(4)$$

where, ${}_1n_2 = \frac{n_2}{n_1}$ is refractive index of second medium i.e., medium of lens with respect to first medium. If the object O is at infinity will be formed at second focus i.e.,

if $u = \infty$ $v = f_2 = f$

Therefore, from equation (4),

$$\frac{1}{f} - \frac{1}{\infty} = ({}_1n_2 - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

i.e., $$\frac{1}{f} = ({}_1n_2 - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \qquad ...(5)$$

This formula is called Lens-Maker's formula.

If first medium is air and refractive index of material of lens be n, then ${}_1n_2 = n$, therefore, the modified equation (5) may be written as

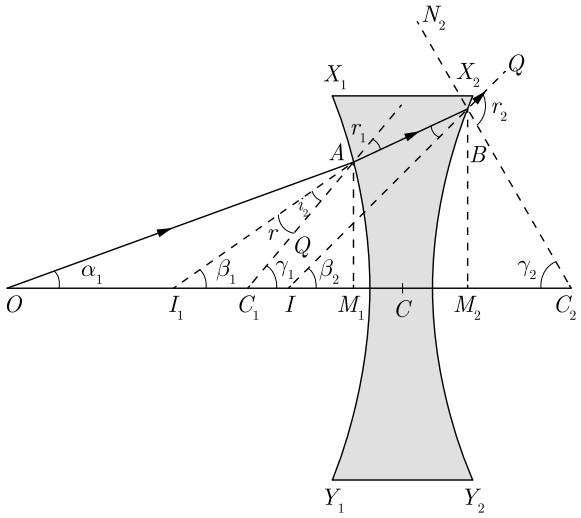
$$\frac{1}{f} = (n - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \qquad ...(6)$$

200. Derive Lens maker's formula for a thin concave lens.

Ans : **Comp 2016**

Let C_1 and C_2 be centres of curvature of two spherical surfaces of the concave lens having optical centre C as shown in the figure. Let μ_2 be the refractive index of the material of the lens and μ_1 that of medium surrounding the lens ($\mu_2 > \mu_1$).

Refraction at Surface $X_1 Y_1$: Let a ray OA starts from the point object O which is placed on the principal axis of the concave lens and it refracts into the denser medium at point A. The refracted ray AB goes undeviating if the lens material were continuous. When AB is produced back it meets at I_1. So I_1 would be the virtual image of point object O.



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$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$$

So, $$\frac{1}{u}=\frac{1}{v}-\frac{1}{f}$$

$$u=\frac{vf}{f-v}=\frac{-25\times 5}{5-(-25)}$$

$$=\frac{-25\times 5}{30}=-4.2\text{ cm}$$

242. A ray of light passes though an equilateral glass prism such that the angle of incidence is equal angle of emergence and each of these angles is equal to $\frac{3}{4}$ of angle of prism. What is the value of deviation?

Ans : **Main 2021**

In prism, $i+e=A+D$

and $i=e=\frac{3}{4}A$ (given)

So, $A+D=\frac{3}{4}A+\frac{3}{4}A$

$$D=\frac{3A}{2}-A=\frac{A}{2}$$

Since, $A=60^\circ$

(being an equilateral glass prism)

So, $D=\frac{60^\circ}{2}=30^\circ$

243. In a pond of water, a flame is held 2 m above the surface of water. A fish is at depth of 4 m from water surface. Refractive index of water is $\frac{4}{3}$. What is the apparent height of the flame from the eyes of fish ?

Ans : **Comp 2008**

Height of flame above water surface,

$$h=2\text{ m}$$

Depth of fish, $d=4\text{ m}$

and refractive index of water,

$$\mu=\frac{4}{3}$$

We know that apparent height of flame above water surface,

$$h'=\mu\times h=\frac{4}{3}\times 2=\frac{8}{3}\text{ m}$$

Therefore, apparent height of the flame from the eyes of fish

$$=d+h'=4+\frac{8}{3}=\frac{20}{3}\text{ m}$$

244. The refractive index of material of prism for blue and red colours are 1.532 and 1.514 respectively. If angle of prism is 8°, what is the angular dispersion produced by the prism?

Ans : **SQP 2009**

Refractive index of lens for blue colour,

$$\mu_B=1.532$$

Refractive index of lens for red colour,

$$\mu_R=1.514$$

and angle of prism,

$$A=8^\circ$$

angular dispersion produced by small-angled prism,

$$d\delta=(\omega_B-\omega_R)A$$

$$=(1.532-1.514)\times 8^\circ$$

$$=0.018\times 8^\circ=0.144^\circ$$

245. Calculate dispersive power of glass, accurately upto three decimal places from following data.

Ans : **Main 2010, 2008**

(i) Refractive index of glass for red colour = 1.60

(ii) Refractive index of glass for yellow colour = 1.61

(iii) Refractive index of glass for violet colour = 1.62

Ans :

Refractive index for violet $\mu_V=1.62$

Refractive index for yellow, $\mu_Y=1.61$

Refractive index for red, $\mu_R=1.60$

Dispersive power, $\omega=\frac{\omega_V-\omega_R}{\omega_Y-1}$

$$=\frac{1.62-1.60}{1.61-1.00}$$

$$=\frac{0.02}{0.61}=0.032$$

246. The focal length of a equi-convex lens is equal to the radius of curvature of either face. What is the value of refractive index of the material of the lens ?

Ans : **SQP 2018**

As we know that,

$$\frac{1}{f}=(\mu-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

$$\frac{1}{f}=(\mu-1)\left(\frac{2}{f}\right)\quad(\text{Since } f=R_1=R_2=R)$$

$$\frac{1}{2}=(\mu-1)$$

$$2(u-1)=1$$

$$u-1=\frac{1}{2}$$

$$u=1+\frac{1}{2}=\frac{3}{2}=1.5$$

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281. Monochromatic light of wavelength 589 nm is incident from air on a water surface. If μ for water is 1.33, find the wavelength, frequency and speed of the refracted light.

Ans : Main 2017, 2015

Wavelength in air,

$$\lambda_a = 589\,\text{nm} = 5.89\times10^{-7}\,\text{m}$$

Refractive index of water,

$$\mu_\omega = 1.33$$

Since, Speed of light in Vacuum,

$$c = 3\times10^8\,\text{m/s}$$

Hence, frequency, $v = \dfrac{c}{\lambda_a} = \dfrac{3\times10^8\,\text{m/s}}{5.89\times10^{-7}\,\text{m}}$

$$= 5.093\times10^{14}\,\text{Hz}$$

Now, Speed of light in water,

$$v = \frac{c}{\mu_w} = \frac{3\times10^8\,\text{m/s}}{1.33}$$

$$= 2.2605\times10^8\,\text{m/s}$$

Hence, Wavelength in water,

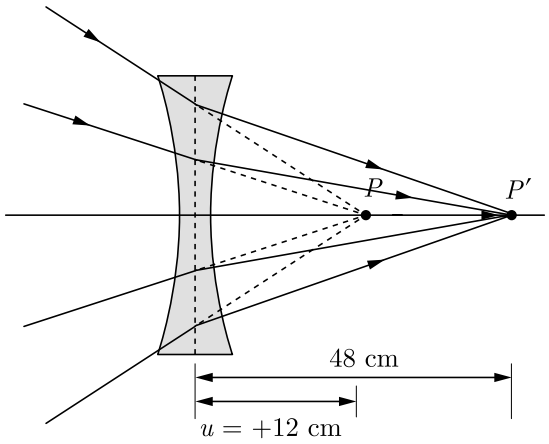
$$\lambda_w = \frac{v_w}{v_a} = \frac{c/\mu_w}{c/\lambda_a} = \frac{\lambda_a}{\lambda_w}$$

(Since, frequency remains the same in all media)

$$= 4.43\times10^{-7}\,\text{m}$$

282. A beam of light converges at a point P. A concave lens of focal length 16 cm is placed in the path of this beam 12 cm from P. Draw a ray diagram and find the location of the point at which the beam would now converge.

Ans : SQP 2013



Given, $u = +12\,\text{cm},\ f = -16\,\text{cm}\ \ v = ?$

Using lens formula,

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

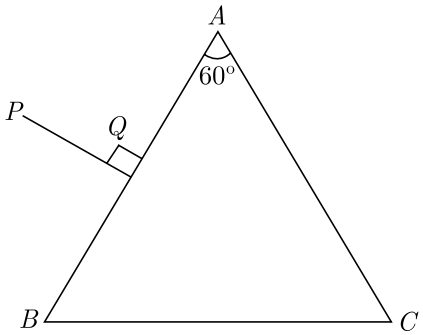
$$-\frac{1}{16} = \frac{1}{v} - \frac{1}{12}$$

$$\frac{1}{v} = \frac{1}{12} - \frac{1}{16} = \frac{4-3}{48} = \frac{1}{48}$$

$$v = +48\,\text{cm}$$

The image of virtual object at P from at P' at a distance 48 cm from the lens.

283. A ray PQ is incident normally on the face AB of a triangular prism of refracting angle of 60° made of a transparent material of refracting index $\frac{2}{\sqrt{3}}$ an shown in the figure. Trace the path of the ray as it passes through the prism. Also, calculate the angle of emergence and angle of deviation



Ans : SQP 2014

If the i_C is the critical angle for the prism.

Now, $\mu = \dfrac{1}{\sin i_C}$

Hence, $\sin i_C = \dfrac{1}{\mu} = \dfrac{\frac{1}{2}}{\sqrt{3}} = \dfrac{\sqrt{3}}{2}$

$$i_C = \sin^{-1}\left(\frac{\sqrt{3}}{2}\right)$$

$$i_C = 60^\circ$$

Angle of incidence at face AC of the prism is 60°. Hence, refracted ray grazes the surface AC.

Angle of emergence $= 90^\circ$

Angle of deviation $= 30^\circ$.

284. A piano-convex lens has radius of curvature 10 cm. Its focal length is 80 cm under water. Calculate the refractive index of the material of the lens, given refractive index of water is 4/3.

Ans : Main 2002

According to lens Maker's formula,

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

But for planoconvex lens, $R_2 = \infty$ and thus

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1}\right)$$

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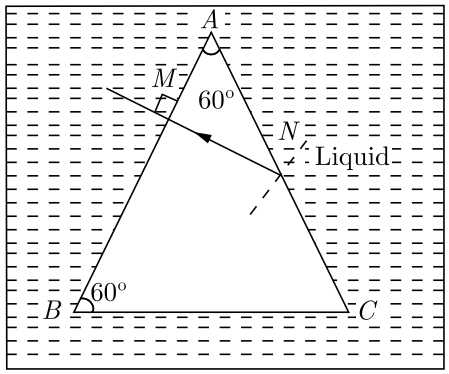
Hence, $v = +100\,\text{cm}$

Thus the image is formed at a distance of 100 cm from the glass surface, in the direction of incident light.

252. Find the refractive index of the liquid if a ray of light strikes surface AB normally and then comes out from face AC at grazing emergence. $({}^{a}\mu_g = 3/2)$



Ans : **Main 2004**

Applying Snell's law at N.

$${}^{a}\mu_g \sin 60^\circ = \mu_2 \sin r$$

$$\frac{3}{2} \times \frac{\sqrt{3}}{2} = \mu_2 \sin 90^\circ$$

$$\mu_2 = \frac{3\sqrt{3}}{4}$$

253. Calculate the focal length of a convex lens whose radii of curvature of two surfaces is 10 cm and 15 cm, respectively and its refractive index is 1.5.

Ans : **Main 2019**

Given,

$$R_1 = +10\,\text{cm},\ R_2 = -15\,\text{cm}$$

and $n = 1.5$

As we know that,

$$\frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

$$\frac{1}{f} = (1.5-1)\left[\frac{1}{10} - \frac{1}{-15}\right]$$

$$= (0.5)\left[\frac{1}{10} + \frac{1}{15}\right]$$

$$= (0.5)\left[\frac{3+2}{30}\right]$$

$$\frac{1}{f} = 0.5\left[\frac{5}{30}\right] = \frac{0.5}{6} = \frac{1}{12}$$

$$f = 12$$

Focal length of convex lens, $f = 12\,\text{cm}$

254. The refractive indices of a material for red, violet and yellow colour lights are 1.52, 1.62 and 1.59 respectively. Calculate the dispersive power of the material. If the mean deviation is 40°, what will be the angular dispersion produced by a prism of this material?

Ans : **Main 2006**

Refractive index of red light, $n_R = 1.52$,

Refractive index of violet light, $n_V = 1.62$,

Refractive index of yellow light, $n_Y = 1.59$

As we know that

So, dispersive power, ω

$$= \frac{n_V - n_R}{n_Y - 1} = \frac{1.62 - 1.52}{1.59 - 1}$$

$$= \frac{0.1}{0.59} = 0.17$$

Angular dispersion,

$$\delta_V - \delta_R = \omega \times \delta_Y$$

255. Two thin convex lenses of focal length 15 cm and 30 cm are placed in contact. What will be power of the combination?

Ans : **Main 2015**

Focal length of first convex lens,

$$f_1 = 15\,\text{cm}$$

Focal length of second convex lens,

$$f_2 = 30\,\text{cm}$$

Focal Length of combination,

$$\frac{1}{f_{eq}} = \frac{1}{f_1} + \frac{1}{f_2}$$

$$= \frac{1}{15} + \frac{1}{30} = \frac{2+1}{30}$$

$$f_{eq} = 10\,\text{cm or } 0.1\,\text{m}$$

We know that,

Power of the lens combination,

$$P = \frac{1}{f_{eq}\,(\text{in meter})}$$

$$= \frac{1}{0.1} = 10\,\text{D}$$

256. Define dispersive power of the material of prism. The refractive indices of a prism for prism for violet, yellow and red colours are 1.632, 1.620 and 1.613 respectively. Calculate the dispersive power of the material of the prism.

Ans : **2005**

Dispersive power of a prism is defined as the ratio of angular dispersion to the mean deviation produced by the prism. It is represented by ω.

Dispersive power,

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$$\omega = \frac{\text{Angular dispersion}}{\text{Mean deviation}}$$

$$\omega = \frac{\delta}{\delta_Y} = \frac{\delta_V - \delta_R}{\delta_Y}$$

$$= \frac{\omega_V - \omega_R}{\omega_Y - 1} \qquad [\delta = \mu - 1]$$

Given, $\mu_V = 1.632$ (refractive index for violet)

$\mu_Y = 1.620$ (refractive index for yellow)

$\mu_R = 1.613$ (refractive index for red)

Thus, $\omega = \frac{1.632 - 1.613}{1.620 - 1} = \frac{0.019}{0.62} = 0.03$

257. An achromatic doublet of focal length 90 cm is to be made of two lenses, the material of one having 1.5 times the dispersive power of the other. The doublet is a converging type. Find the focal length of each of lens.

Ans : **Main 2003, 2001**

We know that condition for achromatism is

$$\frac{\omega_1}{f_1} + \frac{\omega_2}{f_2} = 0$$

where, ω_1 and ω_2 are dispersive powers of two lenses and f_1, f_2 are focal lengths.

$$\frac{\omega_1}{f_1} = -\frac{\omega_2}{f_2} \text{ or } \frac{f_1}{f_2} = -\frac{\omega_1}{\omega_2}$$

$$\frac{f_1}{f_2} = -\frac{\omega_1}{\omega_2} = -1.5 \qquad \text{[given]}$$

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$$

$$\frac{1}{90} = -\frac{1}{1.5 f_2} + \frac{1}{f_2}$$

$$\frac{1}{90} = \frac{-1 + 1.5}{1.5 f_2} = \frac{0.5}{1.5 f_2}$$

$$f_2 = \frac{90 \times 0.5}{1.5} = 30 \text{ cm} \qquad \text{[concave]}$$

$$f_1 = -1.5 \times 30 = -45$$

258. A compound microscope consists of two convex lenses having focal length of 1.5 cm and 5 cm. When an object is kept at a distance of 1.6 cm from the objective, the final image is virtual and lies at a distance of 25 cm from the eyepiece. Calculate magnifying power of the compound microscope in this set-up.

Ans : **Main 2020**

Given, $f_0 = 1.5 \text{ cm}$, $f_e = 5 \text{ cm}$

$u_0 = -1.6 \text{ cm}$ and $v_e = -25 \text{ cm}$

For the objective lens,

$$\frac{1}{f_0} = \frac{1}{v_0} - \frac{1}{u_0}$$

$$\frac{1}{v_0} = \frac{1}{f_0} + \frac{1}{u_0} = \frac{1}{1.5} - \frac{1}{1.6}$$

$$\frac{1}{v_0} = \frac{10}{16 \times 15}$$

$$v_0 = \frac{16 \times 15}{10} = \frac{240}{10} = 24 \text{ cm}$$

Now, magnification, i.e. magnifying power of the microscope,

$$m = -\frac{v_0}{u_0}\left(1 + \frac{D}{f_e}\right)$$

$$= \frac{-24}{-1.6}\left(1 + \frac{25}{5}\right) = 90$$

259. A compound microscope consists of two convex lenses of focal lengths 2 cm and 5 cm. When an object is kept at a distance of 2.1 cm from the objective, a virtual and magnified image is formed 25 cm from the eyepiece. Calculate the magnifying power of the microscope.

Ans : **Main 2016**

Given, $f_0 = 2 \text{ cm}$, $f_e = 5 \text{ cm}$, $u_0 = 2.1 \text{ cm}$,

$v_e = 25 \text{ cm}$, $v_0 = ?$

For the objective lens,

$$\frac{1}{f_0} = \frac{1}{v_0} - \frac{1}{u_0}$$

$$\frac{1}{v_0} = \frac{1}{f_0} + \frac{1}{u_0} = \frac{1}{2} + \left(\frac{1}{-2.1}\right)$$

$$\frac{1}{v_0} = \frac{0.1}{4.2}$$

$$v_0 = 42 \text{ cm}$$

Now, magnification i.e. magnifying power of the microscope,

$$M = \frac{v_0}{u_0}\left(1 + \frac{D}{f_e}\right) = \frac{42}{2.1}\left(1 + \frac{25}{5}\right)$$

$$= 20(6) = 120$$

260. A biconvex lens ($\mu = 1.5$) has equal curvature each of 20 cm. What is the power of the lens?

Ans : **SQP 2012**

Refractive index of lens,

$$\mu = 1.5$$

We know that,

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

where, $R_1 = 20 \text{ cm}$

and $R_2 = -20 \text{ cm}$

$$\frac{1}{f} = (1.5 - 1)\left[\frac{1}{20} - \left(\frac{1}{-20}\right)\right]$$

$$\frac{1}{f} = (1.5 - 1)\left[\frac{1}{20} + \frac{1}{20}\right]$$

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$$\frac{1}{f} = 0.5 \times \frac{1}{10}$$

$$f = \frac{10}{0.5} = 20\,\text{cm}$$

Now, Power of lens

$$P = \frac{1}{f(\text{in meter})}$$

$$= \frac{1}{20} \times 100 = 5\,\text{D}$$

261. Light is incident on a glass plate at an angle of 60°. If reflected and refracted rays are mutually perpendicular, What is the refractive index of the glass plate?

Ans : **SQP 2007**

Angle of incidence, $i = 60^\circ$

We know that

Angle of reflection, $r' =$ Angle of incidence $i = 60^\circ$

Since refracted rays and reflected rays are mutually perpendicular, therefore,

$$r' + r = 90^\circ$$

$$i + r = 90^\circ$$

$$r = 90^\circ - i$$

$$= 90^\circ - 60^\circ = 30^\circ$$

We also know from the Snell's law that refractive index of glass plate,

$$\mu = \frac{\sin i}{\sin r} = \frac{\sin 60^\circ}{\sin 30^\circ}$$

$$= \frac{\frac{\sqrt{3}}{2}}{0.5} = \sqrt{3}$$

262. A double convex lens is manufactured from a glass of refractive index 1.55, with both faces of same radius of curvature. If focal length of lens is to be 20 cm. What is the radius of the curvature of the lens?

Ans : **Main 2010, 2008**

Refractive index of lens,

$$\mu = 1.55$$

Radius of curvature of first face of convex lens,

$$R_1 = R$$

Radius of curvature of second face of convex lens,

$$R_2 = -R$$

Focal length, $f = 20\,\text{cm}$

Relation for the focal length of a double convex lens f is,

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\frac{1}{20} = (1.55 - 1)\left(\frac{1}{R} - \frac{1}{(-R)}\right)$$

$$= 0.55 \times \frac{2}{R} = \frac{1.1}{R}$$

Radius of curvature,

$$R = 20 \times 1.1 = 22\,\text{cm}$$

263. A planoconvex lens is made of refractive index 1.6. The radius of curvature of the curved surface is 60 cm. What is the focal length of the lens?

Ans : **Main 2015**

Refractive index, $\mu = 1.6$

Radius of curvature of curved surface,

$$R_1 = 60\,\text{cm}$$

and radius of curvature of plane side,

$$R_2 = \infty \text{ (due to plane surface)}$$

Relation for the focal length of a planoconvex lens f is,

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$= (1.6 - 1)\left(\frac{1}{60} - \frac{1}{\infty}\right)$$

$$= \frac{0.6}{60} = 0.01$$

$$f = \frac{1}{0.01} = 100\,\text{cm}$$

264. In a planoconvex lens the radius of curvature of the convex lens is 10 cm. If the plane side is polished, What is the focal length lens? (Refractive index $\mu = 1.5$)

Ans : **SQP 2025**

Radius of curvature of curved side,

$$R = 10\,\text{cm}$$

Radius of curvature of plane side,

$$R_2 = \infty \text{ (due to plane surface)}$$

Refractive index, $\mu = 1.5$

Relation for the focal length of a planoconvex lens f is,

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$= (1.5 - 1)\left(\frac{1}{10} - \frac{1}{\infty}\right) = \frac{0.5}{10}$$

$$f = \frac{10}{0.5} = 20\,\text{cm}$$

Therefore, focal length of lens when its plane surface is polished.

$$= \frac{f}{2} = \frac{20}{2} = 10\,\text{cm}$$

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265. A convex lens of focal length 40 cm is in contact with a concave lens of focal length 25 cm. What is the power of the combination?

Ans : SQP 2017, 2011

Focal length of convex lens,

$$f_1 = 40\text{ cm} = 0.4\text{ m}$$

and focal length of concave lens,

$$f_2 = -25\text{ cm} = -0.25\text{ m}$$

Minus sign due to concave lens.

Power of the combination when the lenses are in contact,

$$P = P_1 + P_2 = \frac{1}{f_1} + \frac{1}{f_2}$$

$$= \frac{1}{0.4} + \frac{1}{-0.25} = -1.5\text{ D}$$

266. A double convex lens is made of a glass of refractive index 1.55, with both faces of the same radius of curvature. Find the radius of curvature required, if the focal length is 20 cm.

Ans : SQP 2011

Given, $n = 1.55,\ f = 20\text{ cm}$

$$|R_1| = |R_2| = R\,(\text{let})$$

Since, For double convex lens as $R_1 > 0$ and $R_2 < 0$.

So, $R_1 = R$ and $R_2 = -R$

Using lens maker's formula,

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\frac{1}{20} = (1.55-1).\left(\frac{1}{R} + \frac{1}{R}\right)$$

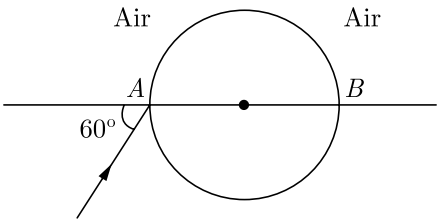
$$\frac{1}{20} = 0.55 \times \frac{2}{R}$$

$$R = 0.55 \times 2 \times 20 = 22\text{ cm}$$

Hence, the radius of curvature is 22 cm.

267. A ray of light falls on a transparent sphere with centre C as shown in figure. The ray emerges from the sphere parallel to the line AB Find the angle of refraction at A if refractive index of the material of the sphere is $\sqrt{3}$.

Ans : SQP 2019



Refractive index, $\mu = \dfrac{\sin i}{\sin r}$

$$\sqrt{3} = \frac{\sin 60^\circ}{\sin r}$$

$$\sin r = \frac{\sqrt{3}}{2} \times \frac{\sqrt{1}}{3} = \frac{1}{2}$$

$$\sin r = \sin 30^\circ$$

$$r = 30^\circ$$

Angle of refraction $= 30^\circ$

268. A convex lens of focal length 5 cm is to be used as a simple microscope. Where should an object be kept, so that image formed by the lens lies at least distance D of distinct vision ($D = 25$ cm)? Also, calculate the magnifying power of this instrument in this set-up.

Ans : Main 2009

When final image formed by a simple microscope, is at the least distance of distinct vision (D), the magnifying power is

$$M = 1 + \frac{D}{f}$$

Given, $f = 5\text{ cm},\ D = -25\text{ cm} = v$

By lens formula, $\dfrac{1}{f} = \dfrac{1}{v} - \dfrac{1}{u}$

$$\frac{1}{u} = \frac{1}{v} - \frac{1}{f}$$

$$= -\frac{1}{25} - \frac{1}{5} = \frac{-1-5}{25} = \frac{-6}{25}$$

$$u = \frac{-25}{6} = -4.166\text{ cm}$$

$$= -4.17\text{ cm}$$

Magnifying power of a simple microscope

$$M = 1 + \frac{D}{f} = 1 + \frac{25}{5} = 6$$

269. Calculate angle of minimum deviation (δ_m) for a regular glass prism.(Take refractive index of glass =1.6).

Ans : Main 2011

Given, $\mu = 1.6,\ \delta_{\min} = ?$

For minimum deviation,

$$\mu = \frac{\sin\left(\frac{A+\delta_{\min}}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

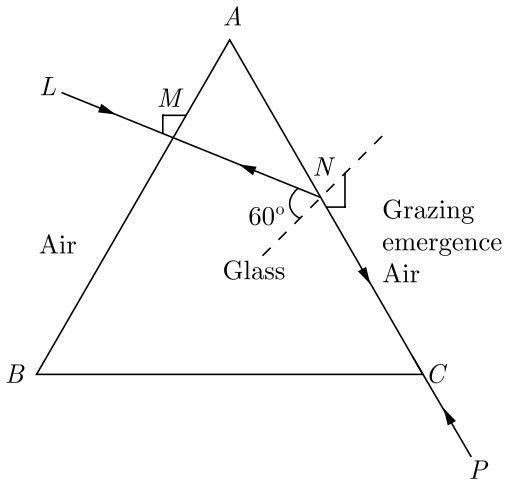
$$1.6 = \frac{\sin\left(\frac{60^\circ+\delta_{\min}}{2}\right)}{\sin\left(\frac{60^\circ}{2}\right)}$$

$$0.8 = \sin\left(\frac{60^\circ + \delta_{\min}}{2}\right)$$

Angle of incidence 60°. This angle will be critical angle for glass-air interface, Now by applying Snell's law.

$$\mu_{\text{glass}} \sin 60^\circ = \mu_{\text{liquid}} \sin 90^\circ$$
$$\frac{60^\circ + \delta_{\min}}{2} = 53.13^\circ$$
$$\delta_{\min} = 46.26^\circ$$

270. A ray LM of monochromatic light incident normally on one refracting surface AB of a regular glass prism ABC emerges in air from the adjacent surface AC as shown in the figure. Calculate the refractive index of the material of the prism.



Ans : **Main 2009, 2005**

By applying Snell's law at point N, we have

$$\mu_{\text{glass}} \sin 60^\circ = \mu_{\text{air}} \sin 90$$

Symbols have their usual meaning

$$\mu_{\text{glass}} \frac{\sqrt{3}}{2} = 1$$
$$\mu_{\text{glass}} = \frac{2}{\sqrt{3}} = 1.15$$

271. The radius of curvature of convex surface of a thin planoconvex lens is 15 cm and refractive index of its material is 1.6. What is the power of lens?

Ans : **Main 2015**

Radius of curvature the convex surface,

$$R_1 = 15 \text{ cm}$$

Radius of plane surface,

$$R_2 = \infty \qquad \text{(due to plane surface)}$$

and refractive index of material,

$$\mu = 1.6$$

Relation for the focal length of a thin planoconvex lens f is,

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$
$$= (1.6 - 1)\left(\frac{1}{15} - \frac{1}{\infty}\right)$$
$$= \frac{0.6}{15} = \frac{1}{25}$$
$$f = 25 \text{ cm} = 0.25 \text{ m}$$

Therefore power of lens,

$$P = \frac{1}{f} = \frac{1}{0.25} = 4 \text{ D}$$

272. The projection lens of a projector has focal length 5 cm. It is desired to get an image with a magnification 30. What is the distance of the screen from the lens?

Ans : **Main 2011**

Focal length of lens, $f = 5 \text{ cm}$

Magnification, $m = 30$

Magnification,

$$m = -\frac{v}{u}$$
$$30 = -\frac{v}{u}$$
$$u = -\frac{v}{30}$$

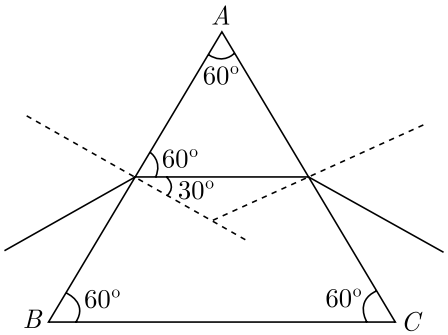
We also know that relation for the distance of screen from the lens v is,

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} = \frac{1}{v} + \frac{30}{v} = \frac{31}{v}$$
$$\frac{1}{5} = \frac{31}{v}$$
$$v = 5 \times 31$$
$$= 155 \text{ cm} = 1.55 \text{ m}$$

273. A ray of light incident on an equilateral glass prism ($\mu_g = \sqrt{3}$) moves parallel to the base line of the prism inside it. Find the angle of incidence for this ray.

Ans : **Main 2012, 2010**

The reflection of light through prism is shown as below



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By geometry Angle of refraction, $r = 30^\circ$

Refractive index, $\mu = \sqrt{3}$

Using Snell's law, $\mu = \dfrac{\sin i}{\sin r}$

$$\sin i = \mu \sin r$$
$$= (\sqrt{3})\sin(30^\circ) = \frac{\sqrt{3}}{2}$$

Angle of incidence, $i = 60^\circ = \dfrac{\pi}{3}$

Hence, $i = \dfrac{\pi}{3}$

274. The velocity of light in glass is $2 \times 10^8\,\text{ms}^{-1}$ and that in air is $3 \times 10^8\,\text{ms}^{-1}$. By how much would an ink dot appear to be raised, when covered by a glass plate 6.0 cm thick?

Ans : **Main 2011**

Given, $v = 2 \times 10^8\,\text{ms}^{-1}$

$c = 3 \times 10^8\,\text{ms}^{-1}$

Refractive index of glass,

$$\mu = \frac{c}{v} = \frac{3 \times 10^8}{2 \times 10^8} = 1.5$$

$$\text{Real depth} = 6.0\,\text{cm}$$

Hence,

$$\text{Apparent depth} = \frac{\text{Real depth}}{\mu}$$
$$= \frac{6.0}{1.5} = 4.0\,\text{cm}$$

Distance through which the ink dot appears to be raised

$$= 6.0 - 4.0 = 2.0\,\text{cm}$$

275. A convex lens of focal length 0.1 m and made of glass ($\mu = 1.5$) is immersed in water ($\mu = 1.33$). What is the change in its focal length?

Ans : **SQP 2008**

Focal length of lens in air,

$$f_a = 0.1\,\text{m}$$

Refractive index of glass,

$$\mu_g = 1.5$$

and refractive index of water,

$$\mu_w = 1.33$$

Focal length of convex lens when immersed in water,

$$f_w = \left[\frac{\mu_g - 1}{(\frac{\mu_g}{\mu_w}) - 1}\right] \times f_a$$
$$= \left[\frac{1.5 - 1}{(\frac{1.5}{1.33}) - 1}\right] \times 0.1$$
$$= \left[\frac{0.5}{1.13 - 1}\right] \times 0.1$$
$$= \frac{0.5}{0.13} \times 0.1 = 0.4\,\text{m}$$

Therefore, change in focal length of the lens

$$= f_w - f_a = 0.4 - 0.1$$
$$= 0.3\,\text{m}$$

276. A compound microscope uses an objective lens of focal length 4 cm and eyepiece lens of focal length 10 cm. An object is placed at 6 cm from the objective lens microscope. Also calculate the length of the microscope.

Ans : **Main 2013**

Given, $f_0 = 4\,\text{cm},\ f_e = 10\,\text{cm},\ u_0 = -6\,\text{cm}$

Magnifying power of microscope,

$$M = -\frac{|v_0|}{|u_0|}\left(1 + \frac{D}{f_e}\right)$$

From lens formula,

$$\frac{1}{f_0} = \frac{1}{v_0} - \frac{1}{u_0}$$
$$\frac{1}{v_0} = \frac{1}{f_0} + \frac{1}{u_0}$$
$$= \frac{1}{4} - \frac{1}{6} = \frac{3-2}{12}$$
$$v_0 = 12\,\text{cm}$$

Hence, $M = -\dfrac{12}{6}\left(1 + \dfrac{25}{10}\right)$

$$= -2 \times 3.5 = -7$$

Negative sign shows that the image is inverted.

Hence, Length of microscope,

$$L = |v_0| + |u_e|$$
$$= 12 + 7.14 = 19.14\,\text{cm}$$

277. A thin symmetrical convex lens of refractive index $\frac{3}{2}$ and radius of curvature 0.3 m is immersed in water of refractive index $\frac{4}{3}$. What is the focal length in water?

Ans : **Comp 2016**

Refractive index of glass,

$$\mu_g = \frac{3}{2}$$

and refractive index of water,

$$\mu_w = \frac{4}{3}$$

Since the lens is symmetrical, therefore radius of curvature of two surfaces of convex lens are,

$$R_1 = 0.3\,\text{m}$$

and $R_2 = -0.3\,\text{m}$

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refractive index of glass with respect to water,

$$^{w}\mu_{g} = \frac{\alpha_g}{\alpha_w} = \frac{\frac{3}{2}}{\frac{4}{3}} = \frac{9}{8}$$

We also know that relation for focal length of convex lens when immersed in water f_w is,

$$\frac{1}{f_w} = (^{w}\mu_{g} - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$
$$= \left(\frac{9}{8} - 1\right)\left(\frac{1}{0.3} + \frac{1}{0.3}\right)$$
$$= \frac{1}{8} \times \frac{2}{0.3}$$
$$= \frac{20}{24} = \frac{10}{12}$$
$$f_w = \frac{12}{10} = 1.2\text{ m}$$

278. For a prism of refractive index 1.732, the angle of minimum deviation is equal to the angle of prism. What is the angle of the prism?

Ans : **SQP 2012, 2010**

Refractive index of prism,

$$\mu = 1.732 = \sqrt{3}$$

and angle of minimum deviation,

$$\delta_m = A$$

(where, A = Angle of prism)

The refractive index of the prism,

$$\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$
$$= \frac{\sin\left(\frac{A+A}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$
$$= \frac{\sin A}{\sin\left(\frac{A}{2}\right)}$$
$$= \frac{2 \cdot \sin\left(\frac{A}{2}\right) \cdot \cos\left(\frac{A}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$
$$= 2\cos\left(\frac{A}{2}\right)$$
$$\sqrt{3} = 2\cos\left(\frac{A}{2}\right)$$
$$\frac{\sqrt{3}}{2} = \cos\left(\frac{A}{2}\right)$$
$$\frac{A}{2} = 30^\circ$$
$$A = 60^\circ$$

279. A biconvex spherical lens has focal length 20 cm. If it is split into two halves to form two piano-convex lenses, what is the focal length of each piano-convex lens?

Ans : **Main 2007**

We know that, $\frac{1}{f} = (\mu - 1)\left(\frac{2}{R}\right)$

$$R = 2f(\mu - 1)$$

Biconvex

Plano-convex

When lens splits $\frac{1}{f_1} = (\mu - 1)\left(\frac{1}{R}\right)$

$$f_1 = \frac{R}{(\mu - 1)} = 2f$$
$$= 2 \times 20 = 40\text{ cm}$$

Hence, focal length gets doubled.

280. A converging lens has a focal length of 20 cm in air. It is made of a material of refractive index 1.6. It is immersed in a liquid of refractive index 1.3. Calculate its new focal length.

Ans : **SQP 2011**

Given, $f_1 = +20\text{ cm}$

$$_{a}n_g = 1.6, {}_{a}n_w = 1.3$$
$$_{w}n_g = \frac{{}_{a}n_g}{{}_{a}n_w} = \frac{1.6}{1.3}$$

Using lens maker's formula (in water) for converging lens,

$$\frac{1}{f_2} = ({}_{w}n_g - 1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right) \quad ...(1)$$

In air, $\frac{1}{f_1} = ({}_{a}n_g - 1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right) \quad ...(2)$

Dividing eq. (2) by eq. (1), we get

$$\frac{f_2}{f_1} = \frac{({}_{a}n_g - 1)}{({}_{w}n_g - 1)}$$
$$= \frac{(1.6 - 1)}{\left(\frac{1.6}{1.3} - 1\right)} = \frac{0.6 \times 1.3}{0.3}$$
$$\frac{f_2}{f_1} = 2.6$$

New focal length, $f_2 = 2.6 \times f_1 = 2.6 \times 20$

$$f_2 = 52\text{ cm}$$

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247. The refractive index of a flint glass for red and blue colours are 1.648 and 1.668 respectively. What is the dispersive power of the lens material?

Ans : **Main 2014**

Refractive index of flint glass for red colour,

$$\mu_R = 1.648$$

and refractive index of flint glass for blue colour,

$$\mu_B = 1.668$$

Mean refractive index of two colours,

$$\mu = \frac{\alpha_B + \alpha_R}{2}$$

$$= \frac{1.668 + 1.648}{2} = 1.658$$

Therefore dispersive power of the lens material,

$$\omega = \frac{\alpha_B - \alpha_R}{\alpha - 1} = \frac{1.668 - 1.648}{1.658 - 1}$$

$$= \frac{0.02}{0.658} = 0.03$$

248. Calculate the distance of an object of height h from a concave mirror of radius of curvature 20 cm, so as to obtain a real image of magnification 2. Find the location of image also.

Ans : **Main 2007**

$$R = -20\,\text{cm} \text{ and } M = -2$$

Focal length, $f = \frac{R}{2} = -10\,\text{cm}$

Magnification, $M = -\frac{v}{u} = -2$ (given)

Hence, $v = 2u$

Using mirror formula,

$$\frac{1}{2u} + \frac{1}{u} = -\frac{1}{10}$$

$$\frac{3}{2u} = -\frac{1}{10}$$

$$u = -15\,\text{cm}$$

Hence, $v = 2 \times (-15)$

$$= -30\,\text{cm}$$

249. Double convex lenses are to be manufacture from a glass of refractive index 1.55 with both faces of the same radius of curvature. What is the radius of curvature required if the focal length is to be 20 cm?

Ans : **SQP 2006**

Refractive index of glass, $\mu = 1.55$

Focal length of lens, $f = 20\,\text{cm}$

Let the radius of curvature of lens are R_1 and R_2. We know that,

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Let, $R_1 = R_2$, then

$R_1 = R$

$R_2 = -R$ (Since, Lens is convex)

$$\frac{1}{20} = (1.55 - 1)\left[\frac{1}{R} - \frac{1}{(R)}\right]$$

$$\frac{1}{20} = 0.55\left[\frac{1}{R} + \frac{1}{R}\right]$$

$$\frac{1}{20} = 0.55 \times \frac{2}{R}$$

$$R = 0.55 \times 2 \times 20 = 22\,\text{cm}$$

250. A thin converging lens of focal length 5cm is used as a simple microscope. Calculate its magnifying power when image formed lies at

(a) Infinity

(b) Least distance of distinct vision ($D = 25$ cm)

Ans : **SQP 2023**

(a) At infinity, $M = \frac{D}{f}$

$$M = \frac{25\,\text{cm}}{5\,\text{cm}}$$

$$M = 5$$

(b) At least distance of distinct vision.

$$M = 1 + \frac{D}{f}$$

$$= 1 + \frac{25}{5}$$

$$= 1 + 5 = 6$$

251. Light from a point source in air falls on a convex spherical glass surface ($\mu = 1.5$, radius of curvature $= 20\,\text{cm}$). The distance of light source from the glass surface is 100 cm. At what position is the image formed?

Ans : **Main 2010**

Given, $\mu_1 = 1$

$\mu_2 = 1.5$

$u = -100\,\text{cm}$

$R = +20\,\text{cm}$

[R is positive for a convex refracting surface]

As, $\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\alpha_2 - \alpha_1}{R}$

Hence, $\frac{1.5}{v} + \frac{1}{100} = \frac{1.5 - 1}{20} = \frac{1}{40}$

or $\frac{3}{2v} = \frac{1}{40} - \frac{1}{100} = \frac{5 - 2}{200} = \frac{3}{200}$

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When the lens is placed in water, then

$$\frac{1}{f_\omega} = (\mu_0 - 1)\left(\frac{1}{R_1}\right)$$

$$= \left(\frac{{}_a\alpha_l}{{}_a\alpha_w} - 1\right)\left(\frac{1}{R_1}\right)$$

On substituting the values, we get

$$\frac{1}{80} = \left(\frac{{}_a\mu_l}{4/3} - 1\right)\left(\frac{1}{10}\right)$$

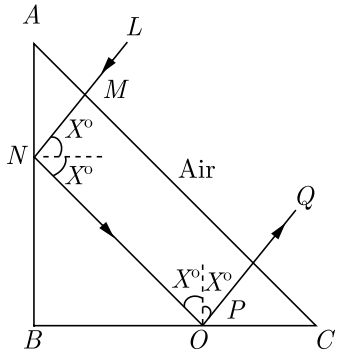
$$\left(\frac{{}_a\mu_l}{4/3} - 1\right) = \frac{10}{80} = \frac{1}{8}$$

$$\frac{{}_a\mu_l}{4/3} = 1 + \frac{1}{8} = \frac{9}{8}$$

$${}_a\mu_l = \frac{9}{8} \times \frac{4}{3}$$

$${}_a\mu_l = \frac{3}{2}$$

285. A ray of light LM incident normally on the surface AC of an isosceles right angled prism ABC (where, $AB = BC$) emerges along PQ, parallel to LM, as shown in the figure below. What can you say about refractive index μ of the material of the prism?



Ans : **Main 2011**

Since, ΔABC is an isosceles right angled prism.

$$\angle A = \angle C = 45^\circ$$

$$\angle x = 45^\circ$$

For total internal reflection to take place at faces AB and BC, $\sin x > \frac{1}{\mu}$

where, μ is the refractive index of prism w.r.t. air.

$$\sin 45^\circ > \frac{1}{\mu}$$

$$\mu > \frac{1}{\sin 45^\circ}$$

$$\mu > \sqrt{2}$$

286. A compound microscope consists of an objective of focal length 2 cm and an eyepiece of focal length 5 cm. When an object is kept 2.4 cm from the objective, final image formed is virtual and 25 cm from the eyepiece. Determine magnifying power of this compound microscope in this set-up i.e. in normal use.

Ans : **Main 2012**

Given, object distance of objective lens

$$u_0 = -2.4\,\text{cm},$$

$$D = 25\,\text{cm},$$

Focal length of eyepiece, $f_e = 5\,\text{cm},$

Focal length of objective, $f_0 = 2\,\text{cm},$

Image distance of objective lens,

$$v_0 = ?$$

Applying lens formula, for objective

$$\frac{1}{v_0} - \frac{1}{u_0} = \frac{1}{f_0}$$

$$\frac{1}{v_0} = \frac{1}{f_0} + \frac{1}{u_0}$$

$$= \frac{1}{2} - \frac{1}{2.4} = \frac{1.2 - 1}{2.4}$$

$$\frac{1}{v_0} = \frac{0.2}{2.4} = \frac{2}{24} = \frac{1}{12}$$

$$v_0 = 12\,\text{cm}$$

Magnifying power, $M = \frac{-v_0}{u_0}\left(1 + \frac{D}{f_e}\right)$

$$= \frac{-12}{-2.4}\left(1 + \frac{25}{5}\right)$$

$$= 5 \times (6) = 30$$

$$M = 30$$

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287. The minimum angular magnification of an astronomical telescope is 10. The length of its tube is 44 cm. Determine the focal length of the objective lens.

Ans : **SQP 2014, 2012**

Angular magnification, $M = 10$

Length of the tube, $L = 44\,\text{cm}$

We know that,

Angular magnification, $M = \frac{f_0}{f_e}$

$$10 = \frac{f_0}{f_e}$$

$$f_0 = 10 f_e \quad \ldots(1)$$

According to the question

Length of tube, $L = f_0 + f_e = 44 \quad \ldots(2)$

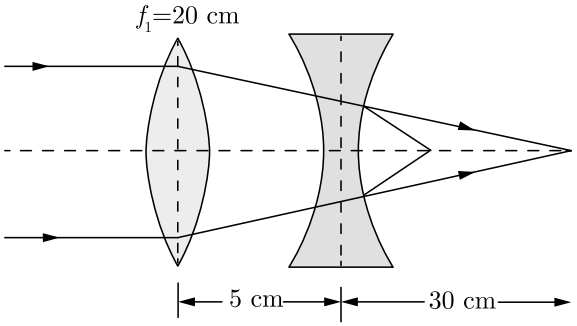
From equation (1), we get

$$10f_e + f_e = 44$$
$$f_e = \frac{44}{11} = 4\,\text{cm}$$

Now, from equation (2), we get

$$f_0 + 4 = 44$$
$$f_0 = 44 - 4$$
$$= 40\,\text{cm}$$

288. See below the diagram.



Calculate the focal length of concave lens with the help of above ray diagram. The focal length of convex lens is 20 cm.

Ans : **Main 2004**

From the ray diagram, it is clear that

object distance $u = (20 - 5) = +15\,\text{cm}$,

Image distance $v = 30\,\text{cm}$

Now, by lens formula

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \quad [f = \text{focal length}]$$
$$\frac{1}{f} = \frac{1}{30} - \frac{1}{15}$$
$$\frac{1}{f} = \frac{1-2}{30}$$
$$f = -30\,\text{cm}$$

289. An object is placed 40 cm from a convex lens of focal length 30 cm . if a concave lens of focal length 50 cm is introduced between the convex lens and the image formed such that it is 20 cm from the convex lens, find the change in the position of the image.

Ans : **Main 2016**

For the convex lens, $f_1 = +30\,\text{cm}$ and object distance $u_1 = -40\,\text{cm}$, therefore,

$$\frac{1}{f_1} = \frac{1}{v_1} - \frac{1}{u_1}$$
$$\frac{1}{+30} = \frac{1}{v_1} - \frac{1}{-40}$$
$$\frac{1}{v_1} = \frac{1}{30} - \frac{1}{40} = \frac{1}{120}$$
$$v_1 = +120\,\text{cm}$$

Real image is formed.

On introducing a concave lens,

$$f_2 = 50\,\text{cm}$$

and $u_2 = 120 - 20$

$= +100\,\text{cm}$ from the concave lens

$$\frac{1}{f_2} = \frac{1}{v_2} - \frac{1}{u_2}$$
$$\frac{1}{-50} = \frac{1}{v_2} - \frac{1}{+100} = -\frac{1}{100}$$
$$v_2 = -100\,\text{cm}$$

A virtual image is formed at the distance of 100 cm from the concave lens.

The change in position between the real image and the virtual image is $100\,\text{cm} + 100\,\text{cm} = +200\,\text{cm}$ to the left of its original position.

290. In a compound microscope, it consists of two convex lenses of focal length 1.5 cm and 10 cm, the object is 2 cm from the objective and the final image is formed at the least distance of distinct vision ($D = 25\,\text{cm}$). Find the distance of separation of the two lenses.

Ans : **Main 2008**

The separation between two lenses can be calculated by the sum of the object distance of eyepiece (u_e) and image distance of objective (v_0).

Given, $f_0 = 1.5\,\text{cm}$, $f_e = 10\,\text{cm}$,

$u_0 = 2\,\text{cm}$, $v_e = -25\,\text{cm} = D$

For eyepiece, $\frac{1}{f_e} = \frac{1}{v_e} - \frac{1}{u_e}$

$$\frac{1}{u_e} = \frac{1}{v_e} - \frac{1}{f_e}$$
$$= -\frac{1}{25} - \frac{1}{10} = -\frac{7}{50}$$
$$u_e = -7.14\,\text{cm}$$

For objective, $\frac{1}{v_0} = \frac{1}{u_0} + \frac{1}{f_0}$

$$= -\frac{1}{2} + \frac{1}{1.5} = \frac{-3+4}{6} = \frac{1}{6}$$
$$v_0 = 6\,\text{cm}$$

Distance of separation

$$= v_0 + u_e$$
$$= (6 + 7.14) = 13.14\,\text{cm}$$

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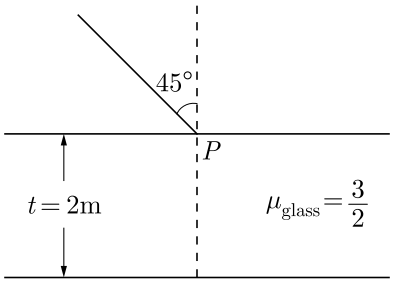
291. The speed of light in vacuum is $c = 3 \times 10^8 \text{ms}^{-1}$. In the given figure $\theta = 45^\circ$ and $\mu_{\text{glass}} = \frac{3}{2}$. Light enters the air-glass interface at P. How much time will light ray take to cross the glass slab?



Ans : SQP 2009

Refractive index of glass,

$$\mu_{\text{glass}} = \frac{3}{2} = 1.5$$

Velocity of light, $c = 3 \times 10^8 \text{ m/sec}$

We know that, velocity of light in glass,

$$c_g = \frac{\text{Velocity of light in air}}{\text{Refractive index of glass}}$$

$$= \frac{3 \times 10^8}{1.5} = 2 \times 10^8 \text{ m/s}$$

Time, $t = \frac{t}{c_g}$

$$= \frac{2}{2 \times 10^8} = 10^{-8} \text{sec}$$

292. A magnifying glass is to be used at the fixed object distance of 1 inch. If it is to produce an erect image 5 times magnified. What is the focal length of magnifying glass ?

Ans : Main 2018, 2014

Given, $u = 1 \text{ inch}$

Magnification, $m = 5$

We know that,

Magnification, $m = \frac{v}{u}$

where, u = Object distance

v = Image distance

$$5 = \frac{v}{u}$$

$$v = 5u \quad (\text{Here, } u = 1 \text{ inch})$$

$$v = 5 \times 1 = 5 \text{ inch}$$

Now, $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$

Using sign convention.

Here, $u = -1 \text{ inch}$

$v = -5 \text{ inch}$

Hence, $\frac{1}{f} = \frac{1}{-5} - \left(\frac{1}{-1}\right)$

$$= 1 - \frac{1}{5} = \frac{4}{5}$$

$$\frac{1}{f} = 0.8 \text{ inch}$$

$$f = \frac{1}{0.8} = 1.25"$$

293. A monochromatic light of wavelength 6000Å in vacuum enters a medium of refractive index 1.5. Calculate the wavelength of light in this medium?

Ans : Main 2016

Wavelength of monochromatic light,

$$\lambda_0 = 6000 \text{ Å}$$

Refractive index of medium,

$$\mu = 1.5$$

As we know $n \propto \frac{1}{\lambda}$

That, n = Refractive index

and λ = Wavelength

So, $\frac{n_1}{n_2} = \frac{\lambda_2}{\lambda_1}$

For Air, $n_1 = 1$

$$\lambda_1 = 6000 \text{ Å}$$

For Glass, $n_2 = 1.5$

$$\lambda_2 = 7$$

$$\frac{1}{1.5} = \frac{\lambda_2}{6000}$$

$$\lambda_2 = 4000 \text{ Å}$$

NODIA

294. A ray of light which is incident in air on the surface of a glass block is deviated through 15°. The angle of incidence in air is 60°. What is the angle of refraction in glass? Also, calculate the critical angle for a glass-air interface.

Ans : Main 2025

We will apply Snell's law at each face.

As $_a\mu_g = \frac{\sin\left(\frac{\delta_m + A}{2}\right)}{\sin\frac{A}{2}}$

$$_a\mu_g = \frac{\sin(60^\circ + 15^\circ)/2}{\sin 60^\circ/2} = \frac{\sin 37.5^\circ}{\sin 30^\circ}$$

$$_a\mu_g = \frac{\sin i}{\sin r}$$

So, $\frac{\sin i}{\sin r} = \frac{\sin 37.5^\circ}{\sin 30^\circ}$

Angle of refraction $= 30^\circ$

Ans :

(i) From lens maker's formula,

$$\frac{1}{f} = ({}_{w}n_{g} - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$= \left(\frac{{}_{a}n_{g}}{{}_{a}n_{w}} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad ...(1)$$

As, ${}_{a}n_{g} < {}_{a}n_{m}$ (1.65) for the first medium with refractive index 1.65.

(ii) And ${}_{a}n_{g} > {}_{a}n_{m}$ (1.33) for the second medium with refractive index 1.33.
Hence, the value of focal length f will be negative in the first medium.

(a) So, the convex lens will behave as the diverging lens for first medium and will behave as the converging lens for the second medium as the sign of the focal length will not mange in second case.

Given, $${}_{a}n_{g} = 1.5,\ {}_{a}n_{w} = \frac{4}{3}$$

$${}_{w}n_{g} = \frac{{}_{a}n_{g}}{{}_{a}n_{w}} = \frac{1.5}{\frac{4}{3}} = \frac{4.5}{4}$$

As, $$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

(b) Hence, $$\frac{f_2}{f_1} = \left(\frac{{}_{a}n_{g} - 1}{{}_{a}n_{w} - 1}\right)$$

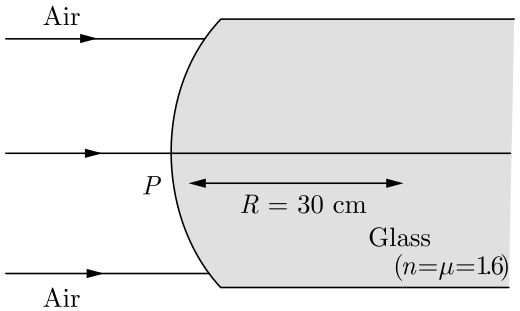
$$= \frac{(1.5-1)}{\left(\frac{4.5}{4} - 1\right)} = \frac{0.5}{\frac{0.5}{4}} = 4$$

$$\frac{f_2}{f_1} = 4$$

$$f_2 = 4f_1$$

Change in focal length $= 4 \quad f_1 - f_1 = 3f_1$.
Change in focal length is equal to thrice of its original focal length.

312. Figure below shows a parallel beam of monochromatic light incident on a convex spherical surface, radius of curvature $R = 30\,\text{cm}$, which separates glass (refractive index = 1.6) from air. Find the position of the image formed due to refraction of light at this single spherical surface.



Ans : **Main 2012, 2010**

According to the question,

$$R = 30\,\text{cm},\ n_2 = 1.6,$$

$$n_1 = 1 \quad \text{[for air]}$$

We know that,

$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$$

Now by putting the values
(symbols have their usual meaning)

$$\frac{1.6}{v} + \frac{1}{\infty} = \frac{1.6-1}{30}$$

$$\frac{1.6}{v} = \frac{0.6}{30}$$

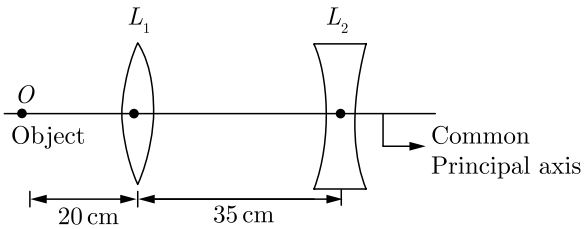
$$\frac{1}{v} = \frac{1}{5 \times 16}$$

$$\frac{1}{v} = \frac{1}{80}$$

$$v = 80\,\text{cm}$$

This position of image is 80 cm from the point P.

313. An illuminated point object O is kept 20 cm from a thin convex lens L_1 of focal length 15 cm as shown below. A thin diverging lens L_2 of focal length 25 cm is kept co-axial with the first lens and 35 cm from it as shown in the figure. Find the position of the final image formed by this combination of lenses.



Ans : **Main 2010**

For convex lens,

$$\frac{1}{f_1} = \frac{1}{v_1} - \frac{1}{u_1}$$

Now by putting the values given in question (symbols have their usual meaning.)

$$\frac{1}{15} = \frac{1}{v_1} - \left(-\frac{1}{20}\right) = \frac{1}{v_1} + \frac{1}{20}$$

$$\frac{1}{v_1} = \frac{1}{15} - \frac{1}{20} = \frac{4-3}{60} = \frac{1}{60}$$

$$v_1 = 60\,\text{cm}$$

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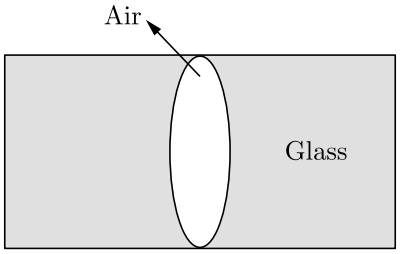
$$30 = \frac{L}{1.25} \times 6$$

$$L = \frac{30 \times 1.25}{6} = 6.25 \text{ cm}$$

Separation between two lenses is 6.25 cm.

298. In the figure, an air lens of radii of curvature ($R_1 = R_2 = 10$ cm) is cut in a cylinder of glass (${}^a\mu_g = 1.5$). What is the focal length and the nature of lens?

Ans : **SQP 2012**



Ans :

Radius of curvature of convex air lens,

$$R_1 = 10 \text{ cm}$$

Radius of curvature of concave air lens,

$$R_2 = -10 \text{ cm}$$

(Minus sign due to concave)

and refractive index of glass to air,

$${}^a\mu_g = 1.5$$

$${}^g\mu_a = \frac{1}{1.5}$$

relation for the focal length of the lens f is,

$$\frac{1}{f} = ({}^g\mu_a - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$= \left(\frac{1}{1.5} - 1\right)\left(\frac{1}{10} - \frac{1}{-10}\right)$$

$$= -\frac{0.5}{1.5} \times \frac{1}{5} = -\frac{1}{15}$$

$$f = -15 \text{ cm}$$

Minus sign of focal length shows the air lens is a concave type.

Therefore the focal length of air lens is 15 cm and it is a concave lens.

299. A concave mirror of focal length 12 forms a three times magnified virtual image of an object. Find the distance of the object from the mirror. The focal lengths of the objective the eye-piece of a compound micros are 1.0 cm and 2.5 cm respectively. Find the tube length of the microscope obtaining a magnification of 300.

Ans : **Main 2023, 2018**

$m = +3$ (virtual image)

For mirror,

$$m = \frac{-v}{u}$$

$$\frac{-v}{u} = 3$$

$$v = -3u \quad \ldots(1)$$

By mirror formula

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$$

$$\frac{1}{-12} = \frac{1}{-3u} + \frac{1}{u}$$

$$\frac{-1}{12} = \frac{2}{3u}$$

$$u = -8 \text{ cm}$$

Hence, object is placed at a distance of 8 cm from the mirror.

Magnification of compound microscope

$$m = m_0 \times m_e = \left(\frac{L}{f_0} \times \frac{D}{f_e}\right)$$

Here, $L = ?$, $D = 25$ cm

$f_0 = 1$ cm and $f_e = 2.5$ cm, $m = 300$

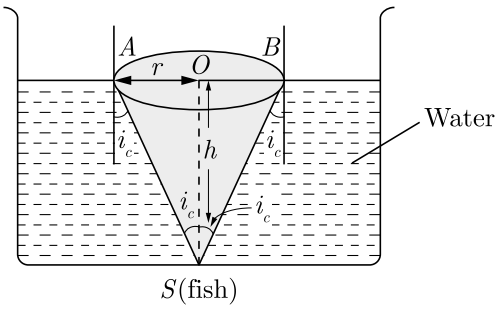
$$300 = \left(\frac{L}{1} \times \frac{25}{2.5}\right)$$

$$L = \frac{300 \times 2.5}{25} = \frac{300}{10} = 30 \text{ cm}$$

300. A fish is at a depth of $\sqrt{7}$ cm and it can see only through a circular section of water surface. What will be radii of this circular surface? The refractive index of water with respect to air is $\frac{4}{3}$. Sketch the diagram also.

Ans : **SQP 2016**

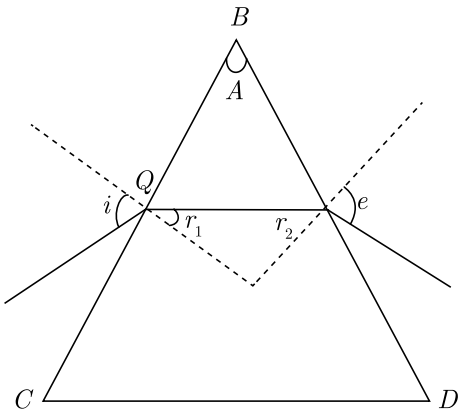
Suppose the height $OS = h$ is such that $\angle OSA = i_c$. Then any other ray from S (fish) will be totally internally reflected because then the angle of incidence would be greater than i_c.



In ΔOSA, $\sin i_c = \frac{OA}{AS} = \frac{r}{\sqrt{r^2 + h^2}}$

NODIA

Angle of emergence, $e = 60^\circ$



For face BC, $$n = \frac{\sin i}{\sin r_1}$$

$$1.52 = \frac{\sin 40^\circ}{\sin r_1}$$

$$\sin r_1 = \frac{\sin 40^\circ}{1.52} = \frac{0.642}{1.52}$$

$$\sin r_1 = 0.4223$$

$$r_1 = \sin^{-1}(0.4223) = 24.98$$

Again, for face BD,

$$\frac{\sin r_2}{\sin e} = \frac{1}{n}$$

$$\frac{\sin r_2}{\sin 60^\circ} = \frac{1}{1.52}$$

$$\sin r_2 = \frac{2}{1.52} = \frac{0.8660}{1.52}$$

$$r_2 = \sin^{-1}(0.569) = 34.68$$

Angle of prism, $$A = r_1 + r_2$$

$$= 24.98^\circ + 34.68^\circ$$

$$= 59.66^\circ \simeq 60^\circ$$

307. A ray EF of monochromatic light is incident on the refracting surface AB of a regular glass prism (refractive index =1.5) at an angle of incidence of $i = 55^\circ$. If it emerges through the adjacent face AC, calculate the angle of emergence 'e'.

Ans : **Main 2010**

At F, applying Snell's law

$$\frac{\sin i}{\sin r_1} = \mu = 1.5$$

$$i = 55^\circ$$

$$\sin r_1 = \frac{\sin 55^\circ}{1.5} = 0.5461$$

Now, $$r_1 = \sin^{-1}(0.5461) = 33.1^\circ$$

$$r_1 + r_2 = A$$

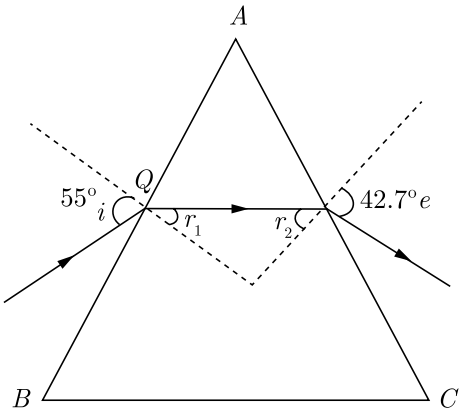
$$r_2 = 60^\circ - 33.1^\circ = 26.9^\circ$$

At G, $$\frac{\sin e}{\sin r_2} = \mu = 1.5$$

$$\sin e = 1.5 \times \sin 26.9^\circ$$

$$= 1.5 \times 0.453 = 0.68$$

$$e = 42.7^\circ$$



308. The total magnification produced by a compound microscope is 20. The magnification produced by the eyepiece is 5. The microscope is focussed on a certain object. The distance between the objective and eyepiece is observed to be 14 cm. If least distance of distinct vision is 20 cm, calculate the focal length of the of objective and the eyepiece.

Ans : **Main 2008, 2001**

Here, $M = -20, m_e = 5, v_e = -20$ cm

For eyepiece, $$m_e = \frac{v_e}{u_e}$$

$$5 = \frac{-20}{u_e}$$

$$u_e = \frac{-20}{5} = -4 \text{ cm}$$

Using lens formula,

$$\frac{1}{v_e} - \frac{1}{u_e} = \frac{1}{f_e}$$

$$-\frac{1}{20} + \frac{1}{4} = \frac{1}{f_e}$$

$$\frac{-1+5}{20} = \frac{1}{f_e}$$

$$f_e = 5 \text{ cm}$$

Now, total magnification,

$$M = m_e \times m_0$$

$$-20 = 5 \times m_0$$

$$m_0 = -4$$

Also, $$|v_0| + |u_e| = 14$$

$$|v_0| + |-4| = 14$$

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Now, for biconvex lens,

$$\frac{1}{10} = (\mu - 1)\left(\frac{1}{R} + \frac{1}{R}\right)$$

$$= \frac{2(\mu - 1)}{R}$$

$$R = 20(\mu - 1)$$

For plano-convex lens

$$\frac{1}{f_1} = (\mu - 1)\left(\frac{1}{R} - \frac{1}{\infty}\right)$$

$$f_1 = \frac{1}{\mu - 1} \times R$$

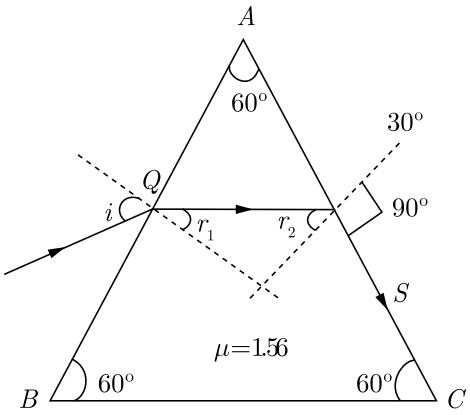
$$= \frac{1}{\alpha - 1} \times 20(\alpha - 1)$$

$$f_1 = 20 \text{ cm}$$

304. Find the angle of incidence at which a ray of monochromatic light should be incident on the first surface AB of a regular glass prism ABC so that the emergent ray grazes the adjacent surface AC.
(Refractive index of glass = 1.56)

Ans : **Main 2016**

According to the question,



The refracted ray RS will just suffer total internal reflection or grazes the surface AC. If it is incident at the critical angle i_c.

i.e. $r_2 = i_c$

Now, for face AC

$$\sin i_c = \frac{1}{\mu} = \frac{1}{1.56}$$

$$i_c = r_2 = 41^\circ$$

But $r_2 + r_1 = A$

$$r_1 = A - r_2 = A - i_c$$

$$= 60^\circ - 41^\circ = 19^\circ$$

From Snell's law, $\mu = \frac{\sin i}{\sin r_1}$

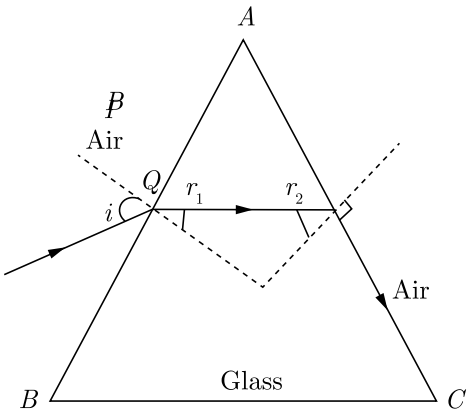
$$\sin i = \mu \sin 190^\circ$$

$$= 1.56 \times 0.325 = 0.507$$

$$i = \sin^{-1} 0.507 \approx 30^\circ$$

Thus, angle of incidence, $i \approx 30^\circ$

305. At what angle, a ray of light should be incident on the first face AB of a regular glass prism ABC, so that the emergent ray grazes the adjacent face AB ?
(Refractive index of glass = 1.6)



Ans : **Main 2013**

At face AC, by Snell's law

$$\sin r_2 = \frac{1}{{}_a\mu_g}$$

$$\sin r_2 = \frac{1}{1.6}$$

$$r_2 = \sin^{-1}\left(\frac{1}{1.6}\right)$$

$$r_2 = 38.68^\circ$$

and $r_1 + r_2 = A$ [A = Angle of prism]

$$r_1 = 60^\circ - 38.68^\circ = 21.32^\circ$$

At face AB, by Snell's law, we have

$$\frac{\sin i}{\sin r} = {}_a\mu_g$$

$$\sin i = \sin r_1 \times {}_a\mu_g = \sin 21.32^\circ \times 1.6$$

$$\sin i = 0.5817$$

$$i = \sin^{-1}(0.5817)$$

$$i = 35.57^\circ$$

306. A ray of light is incident on a prism whose refractive index is 1.52 at an angle of 40°. If the angle of emergence is 60°, calculate the angle of the prism.

Ans : **Main 2019, 2017**

Given, refractive index, $n = 1.52$

Angle of incidence, $i = 40^\circ$

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For refractive index

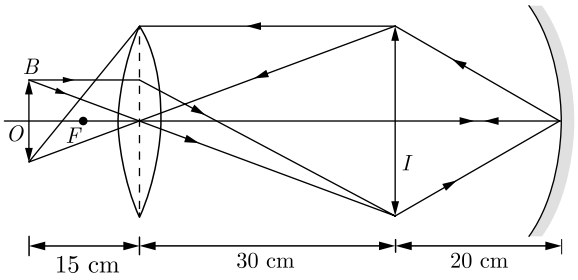
$$
\begin{aligned}
{}_a\mu_g &= \frac{\sin\left(\frac{\delta_{\min}+A}{2}\right)}{\sin\left(\frac{A}{2}\right)} \\
\delta_{\min} &= 15^\circ,\ \angle i = 60^\circ \\
{}_a\mu_g &= \frac{\sin(60^\circ+15^\circ)/2}{\sin 60/2^\circ} \\
&= \frac{\sin 37.5^\circ}{\sin 30^\circ} = 1.217 \\
\sin i_c &= \frac{1}{{}_a\mu_g} \quad [i_c = \text{Critical angle}] \\
\sin i_c &= \frac{1}{1.217} \\
&= \sin^{-1}0.821^\circ = 55.2
\end{aligned}
$$

295. An object is placed 15 cm in front of a convex lens of focal length 10 cm. Find the nature and position of the image formed. Where should a concave mirror of radius of curvature 20 cm be placed so that the final image is formed at the position of the object itself ?

Ans : SQP 2013, 2009

For lens, $u = -15\,\text{cm}$,

$f = +10\,\text{cm}$



$$
\begin{aligned}
\frac{1}{f} &= \frac{1}{v} - \frac{1}{u} \\
\frac{1}{v} &= \frac{1}{f} + \frac{1}{u} \\
&= \frac{1}{10} - \frac{1}{15} \\
v &= 30\,\text{cm}
\end{aligned}
$$

For image to be formed at O, the rays incident on mirror should form the image at centre of curvature. It will be so if the image I formed by the lens lies at the centre of curvature of the mirror.

Hence, $d = |v| + |R| = 30 + 20 = 50\,\text{cm}$

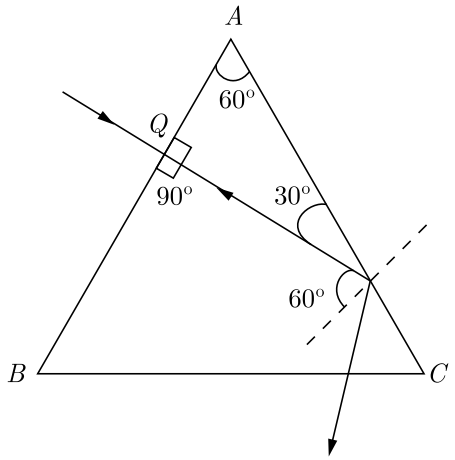
The image is inverted.

296. A ray of light is normally incident on one face of an equilateral prism. Trace the course of the ray through the prism and emerging from it.

Ans : Main 2003

For glass prism,critical angle is

$$
\begin{aligned}
i_c &= \sin^{-1}\left(\frac{1}{\mu}\right) = \sin^{-1}\left(\frac{1}{3/2}\right) \\
&= \sin^{-1}\left(\frac{2}{3}\right) = 42^\circ
\end{aligned}
$$



Now, consider the diagram. Angle of incidence on the face AC, $i = 60^\circ > i_C$.

Hence, the ray is totally internally reflected.

297. You are given two converging lenses of focal length 1.25 cm and 5 cm to design a compound microscope. If it is desired to have a magnification of 30, find out the separation between the objective and the eyepiece.

Ans : Comp 2015, 2010

The magnification due to the objective lens,

$$m_0 = \frac{v_0}{u_0}$$

If the object is close to focus of the objective lens then,

$$u_0 = f_0 \text{ and } v = L$$

(where, L = distance between two lenses)

$$m_0 = \frac{L}{f_0}$$

If the final image is at the near point,then magnification due to eye lens's

$$m_e = \left(1 + \frac{D}{f_e}\right)$$

$$M = m_0 \times m_e = \frac{L}{f_0}\left(1 + \frac{D}{f_e}\right)$$

Use, $f_0 = 1.25\,\text{cm}$ and $f_e = 5\,\text{cm}$

$$30 = \frac{L}{1.25}\left(1 + \frac{25}{5}\right)$$

NODIA

$$v_0 = 14 - 4 = 10\,\text{cm}$$

$$m_0 = 1 - \frac{v_0}{f_0} - 4 = 1 - \frac{10}{f_0}$$

$$-5 = -\frac{10}{f_0}$$

$$f_0 = 2\,\text{cm}$$

309. State how focal length of a glass lens (refractive index 1.56) changes when it is completely immersed in

(i) water (refractive index = 1.33)

(ii) a liquid (refractive index = 1.65).

Ans : **Main 2016, 2015**

According to the question,

$$\mu_{\text{glass}} = 1.56$$

$$\mu_{\text{water}} = 1.33$$

$$\mu_{\text{liquid}} = 1.65$$

From lens maker formula,

$$\frac{1}{f} = \left(\frac{\alpha_2}{\alpha_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

For air, $\frac{1}{f} = (\mu_2 - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ ...(1)

(i) For water,

$$\frac{1}{f_w} = \left(\frac{\mu_2}{1.33} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad ...(2)$$

On dividing of Eq. (1) by Eq. (3), we get

$$\frac{f_w}{f} = \frac{(\mu_2 - 1)}{\left(\frac{\mu_2}{1.33} - 1\right)}$$

$$f_w = f\left(\frac{(\mu_2 - 1)}{\frac{\mu_2}{1.33} - 1}\right)$$

$$= \frac{f(1.56 - 1)}{\frac{1.5}{1.3} - 1} = 3.33f$$

Focal length is positive and it becomes 3.33 times, so the nature of lens remains same.

(ii) For liquid,

$$\frac{1}{f_l} = \left(\frac{\mu_2}{1.65} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad ...(3)$$

On dividing of Eq. (1) by Eq. (3), we get

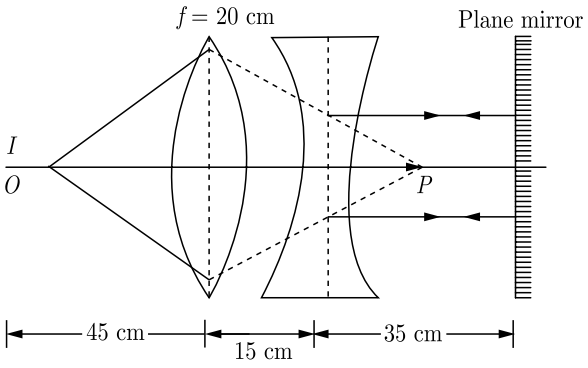
$$\frac{f_l}{f} = \frac{(\alpha_2 - 1)}{\left(\frac{\alpha_2}{1.65} - 1\right)}$$

$$= f\left(\frac{1.5 - 1}{\frac{1.5}{1.65} - 1}\right)$$

$$= -\frac{0.5f}{0.09} = 5.55f \quad \text{(approx)}$$

Focal length becomes 5.55 times and is negative i.e. nature of lens get reversed.

310. The figure below shows the positions of a point object O, two lenses, a plane mirror and the final image I which coincides with the object. The focal length of the convex lens is 20 cm. Calculate the focal length of the concave lens.



Ans : **Main 2014**

The image formed by the lens will act as object and by applying lens formula for the different lens, we will get the focal length of concave lens.

For convex lens, $f = 20\,\text{cm}$, $u = -45\,\text{cm}$

and $v = ?$

By lens formula,

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

Symbols have their usual meaning

$$\frac{1}{v} - \frac{1}{(-45)} = \frac{1}{20}$$

$$v = 36\,\text{cm}$$

For concave lens, $u = 36 - 16 = 20\,\text{cm}$, $v = \infty$

and $f = ?$

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

$$\frac{1}{\infty} - \frac{1}{20} = \frac{1}{f}$$

$$f = -20\,\text{cm}$$

Negative sign shows that lens is concave.

311. A convex lens made up of a glass of refractive index 1.5 is dipped in turn in :

Ans : **Comp 2006, 2001**

(i) a medium of refractive index 1.65.

(ii) a medium of refractive index 1.33.

(a) Will it behave as a converging lens or a diverging lens in the two cases?

(b) How will its focal length change in the two media?

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Here, $\mu = \frac{4}{3}$

$h = \sqrt{7}\,\text{cm}$

Hence, $\frac{3}{4} = \frac{r}{\sqrt{r^2 + (\sqrt{7})^2}}$

On taking square both side, we get

$$\frac{9}{16} = \frac{r^2}{r^2+7}$$
$$9r^2 + 63 = 16r^2$$
$$16r^2 - 9r^2 = 63$$
$$7r^2 = 63$$
$$r = \sqrt{9}$$
$$= 3\,\text{cm}$$

301. Two thin lenses of powers 5 D and 2 D are placed coaxially at a distance 20 cm apart. Find the focal length and power of the combination of lenses.

Ans : **SQP 2013, 2012**

Power of first lens, $P_1 = 5\,\text{D}$

Power of second lens, $P_2 = 2\,\text{D}$

Distance between the lens,

$d = 20\,\text{cm}$

Focal length of first lens,

$$f_1 = \frac{1}{P_1} \times 100\,\text{cm}$$
$$= \frac{1}{5} \times 100 = 20\,\text{cm}$$

Similarly, $f_2 = \frac{1}{P_2} \times 100$

$$= \frac{1}{2} \times 100 = 50\,\text{cm}$$

We know that,

Focal length of combination of lens,

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$$
$$\frac{1}{f} = \frac{1}{20} + \frac{1}{50} - \frac{20}{20 \times 50}$$
$$\frac{1}{f} = \frac{1}{20}$$
$$f = 20\,\text{cm}$$

Power of lens combination,

$$P = \frac{1}{f(\text{meter})}$$
$$= \frac{1}{20} \times 100$$
$$= 5\,\text{D}$$

302. A plano-convex lens made of glass ($n = 1.5$) has a focal length 10 cm.

(i) Calculate the radius of curvature of its curved surface.

(ii) If an identical plano-convex lens is placed in contact with the first (plane surfaces facing each other), what will be the power (in dioptres) of the combination?

Ans : **Main 2007, 2012**

(i) Given, refractive index $n = 1.5$,

focal length, $f = 10\,\text{cm}$

Applying lens maker's formula,

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$
$$\frac{1}{10} = (1.5-1)\left(\frac{1}{R_1}\right)$$

[for planoconvex lens, $R_2 = \infty$]

Because 2nd surface is plane.

$$\frac{1}{10} = \frac{0.5}{R_1}$$
$$R_1 = 5\,\text{cm}$$

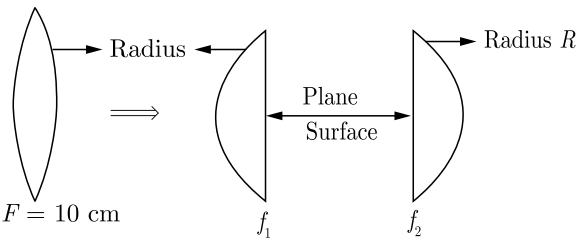
(ii) When two planoconvex lenses are placed side by side, this combination acts as biconvex lens. Now, by lens maker's formula,

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$
$$\frac{1}{f} = (n-1)\frac{2}{R_1} = \frac{0.5 \times 2}{5} = \frac{1}{5}$$

$[R_1 = R = R_2 = 5\,\text{cm}]$

$$f = 5\,\text{cm} = 0.05\,\text{m}$$
$$\text{Power, } P = \frac{1}{f(m)} = \frac{100}{5} = +20\,\text{D}$$

303. An equi-convex lens of glass having focal length of 10 cm is split into two identical plan-convex lenses each having focal length f_1 as shown below. Find the value of f_1.



Ans : **Main 2010**

As, we know from lens maker's formula that,

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

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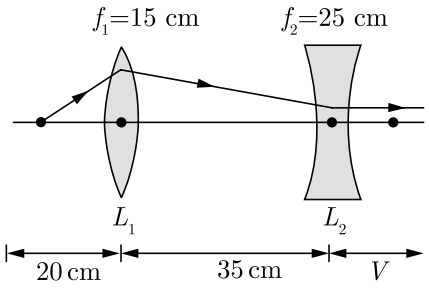


For concave lens, $v_1 = u_2 = 25\,\text{cm}$

$$= (60\,\text{cm} - 35\,\text{cm})$$

$$\frac{1}{f_2} = \frac{1}{v_2} - \frac{1}{u_2}$$

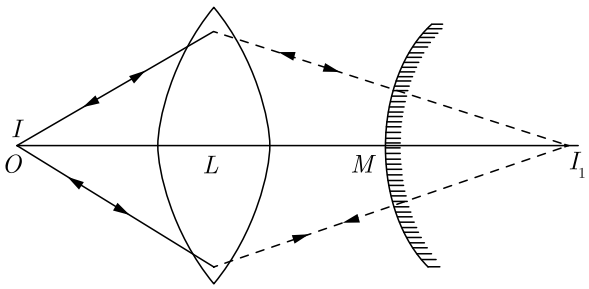
$$\frac{1}{-25} = \frac{1}{v_2} - \frac{1}{25}$$

$$\frac{1}{v_2} = 0$$

$$v_2 = \infty$$

The final image is at infinity.

314. A point object O is placed at a distance of 15 cm from a convex lens L of focal length 10 cm as shown in the figure below. On the other side of the lens, a convex mirror M is placed such that its distance from the lens is equal to the focal length of the lens. The final image formed by this combination is observed to coincide with the object O. Find the focal length of the convex mirror.



Ans : **Main 2015**

Given, $u = -15\,\text{cm}$,

$f = 10\,\text{cm}$,

$d = f = 10\,\text{cm}$ (Convex lens)

For lens, $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

Substituting the all values,

$$\frac{1}{v} - \frac{1}{(-15)} = \frac{1}{10} \qquad (u = -15\,\text{cm})$$

$$\frac{1}{v} = \frac{1}{10} - \frac{1}{15} = \frac{3-2}{30} = \frac{1}{30}$$

$$v = 30\,\text{cm}$$

$$MI = LI - LM = 30 - 10 = 20\,\text{cm}$$

Now, the focal length,

$$f = \frac{20}{2} = 10\,\text{cm}$$

315. A thin convex lens which is made of glass (refractive, index 1.5) has a focal length of 20 cm. It is now completely immersed in a transparent liquid having refractive index 1.75. Find the new focal length of the lens.

Ans : **Main 2009**

We have to apply lens maker's formula separately for each case.

According to the question,

refractive index of glass w.r.t. air

$${}_a\mu_g = 1.5,$$

Focal length for initial case, $f = 20$ cm,

Refractive index of liquid w.r.t. air ${}_a\mu_l = 1.75$

So, from lens marker's formula

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\frac{1}{R_1} - \frac{1}{R_2} = C \qquad [\text{say}]$$

where, $\mu =$ relative refractive index, R_1 and R_2 are radii of curvatures.

$$\frac{1}{f} = (\mu - 1)\,C$$

In air, $\frac{1}{f} = ({}_a\mu_g - 1)\,C$ ...(1)

In liquid, $\frac{1}{f_1} = ({}_l\mu_g - 1)\,C$

$$\frac{1}{f_1} = \left(\frac{{}_a\mu_g}{{}_a\mu_l} - 1\right)C \qquad ...(2)$$

On dividing Eq. (i) by Eq. (2), we get

$$\frac{1/f}{1/f_1} = \frac{{}_a\mu_g - 1}{\frac{{}_a\mu_g}{{}_a\mu_l} - 1} = \frac{1.5 - 1}{\frac{1.5}{1.75} - 1}$$

$$\frac{f_l}{f} = \frac{0.5 \times 1.75}{1.5 - 1.75}$$

$$f_l = \frac{0.5 \times 1.75}{-0.25} \times 20$$

$$f_l = -70\,\text{cm} \qquad [\text{concave}]$$

316. In the figure, ABC is the cross-section of a right angled prism with angle $B = 60°$ and angle $A = 30°$. PQ is a ray incident normally at Q. Copy the diagram and complete the passage of the ray through the prism. Explain briefly what happens at the interfaces between glass and air? Calculate sin i_2, where i_2 is the angle of emergence in air. Take critical angle for glass as 42° and refractive index of glass is 1.5.

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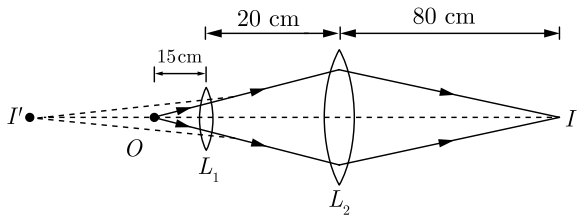
335. In the following diagram, an object O is placed 15 cm in front of a convex lens L_1 of focal length 20 cm and the final image is formed at I at a distance of 80 cm from the second lens L_2. Find the focal length of the L_2.



Ans : **Main 2010**

Let focal length of lens L_2 be x cm.

Now, for lens L_1,

$$u = -15;\ f = +20\text{ cm},\ v = ?$$

Now, using lens formula,

$$\frac{1}{v} - \frac{1}{u} + \frac{1}{f}$$

$$\frac{1}{v} = \frac{1}{f} + \frac{1}{u}$$

$$= \frac{1}{20} + \frac{1}{-15} = \frac{15-20}{300}$$

$$= -\frac{5}{300} = -\frac{1}{60}$$

$$v = -60\text{ cm}$$

i.e., -60 cm from lens in the direction of object.

Now, for lens L_2,

The image formed by lens L_1, will act as object for lens L_2,

$$u = -60 + (-2) = -80\text{ cm}$$

$$v = +80\text{ cm} \qquad \text{(given)}$$

and $$f = x\text{ cm}$$

Applying lens formula for lens L_2,

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

$$\frac{1}{x} = \frac{1}{80} - \frac{1}{(-80)} = \frac{1}{80} + \frac{1}{80}$$

$$\frac{1}{x} = \frac{2}{80}$$

$$x = 40$$

Hence, focal length of lens L_2 is 40 cm.

336. An object is placed (1) 10 cm, (2) 5 cm in front of a concave mirror of radius of curvature 15 cm. Find the position, nature and magnification of the image in each case.

Ans : **SQP 2012**

As R is negative for a concave mirror, so

$$f = \frac{R}{2} = -\frac{15}{2} = -7.5\text{ cm}$$

1. Here object distance,

$$\mu = -10\text{ cm}$$

By mirror formula,

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{-7.5} - \frac{1}{-10}$$

$$= \frac{-2.5}{7.5 \times 10} = -\frac{1}{30}$$

$$v = -30\text{ cm}$$

As v is negative a real image is formed 30 cm from the mirror on the same side as the object.

Magnification,

$$m = -\frac{v}{u} = -\frac{-30}{-10} = -3$$

The image is magnified, real and inverted.

2. Here object distance,

$$u = -5\text{ cm}$$

By mirror formula,

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{-7.5} - \frac{1}{-5}$$

$$= \frac{-5+7.5}{7.5 \times 5} = \frac{1}{15}$$

$$v = +15\text{ cm}$$

As v is positive a virtual image is formed 15 cm behind the mirror.

Magnification,

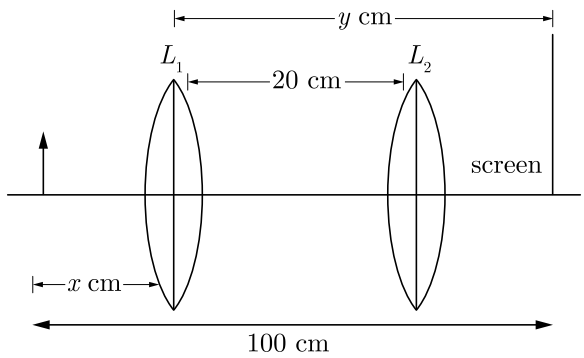
$$m = -\frac{v}{u} = -\frac{15}{-5} = 3$$

The image is magnified, virtual and erect.

337. A screen is placed at a distance of 100 cm from of object. The image of the object is formed on the screen by a convex lens for two different locations of the lens separated by 20 cm. Calculate the focal length of the used.

Ans : **Comp 2012**

For first position of the lens, we have



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Hence, $\frac{1}{u}+\frac{1}{3u} = -\frac{1}{15}$

$$\frac{4}{3u} = -\frac{1}{15}$$

$$u = -\frac{15\times 4}{3} = -20\text{ cm}$$

When the image formed is virtual,

$$m = \frac{h_2}{h_1} = -\frac{v}{u} = +3$$

$$v = -3u$$

As $\frac{1}{u}+\frac{1}{v} = \frac{1}{f}$

$$\frac{1}{u}-\frac{1}{3u} = -\frac{1}{15}$$

$$\frac{2}{3u} = -\frac{1}{15}$$

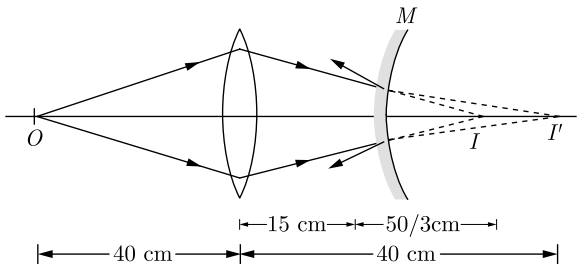
Hence, $u = -\frac{15\times 2}{3} = -10\text{ cm}$

319. A convex lens of focal length 20 cm is placed coaxially with a convex mirror of radius of curvature 20 cm. The two are kept 15 cm apart. A point object is placed 40 cm in front of the convex lens. Find the position of the image formed by this combination. Draw the ray diagram showing the image formation.

Ans : **Main 2016, 2010**

For convex lens,

$$u = -40\text{ cm},\ f = 20\text{ cm}$$



$$\frac{1}{f} = \frac{1}{v}-\frac{1}{u}$$

$$\frac{1}{20} = \frac{1}{v}-\frac{1}{-40}$$

$$\frac{1}{v} = \frac{1}{20}-\frac{1}{40}$$

$$v = 40\text{ cm}$$

This image acts as a virtual object for the convex mirror.

$$u = 40-15 = 25\text{ cm}$$

$$f = \frac{20}{2} = +10\text{ cm}$$

Using mirror formula,

$$\frac{1}{f} = \frac{1}{v}+\frac{1}{u}$$

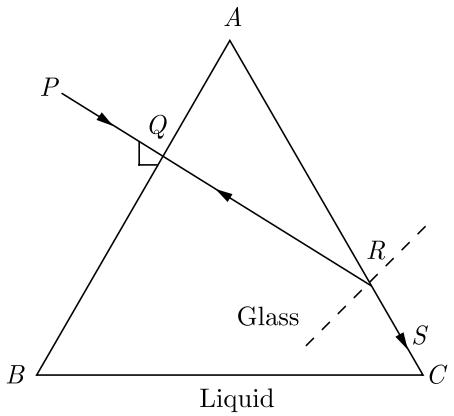
$$\frac{1}{10} = \frac{1}{v}+\frac{1}{25}$$

$$\frac{1}{v} = \frac{1}{10}-\frac{1}{25}$$

$$v = \frac{15}{3}\text{ cm} = 16.67\text{ cm}$$

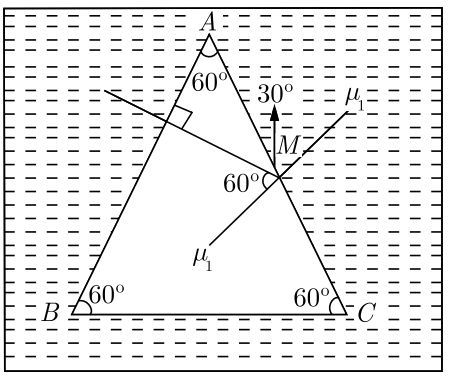
Hence, the final image is a virtual image formed at a distance of 16.67 cm.

320. A narrow beam of monochromatic light PQ is incident normally on one face of an equiangular glass prism of refractive index 1.45. When the prism is immersed in a certain 'liquid, the ray makes a grazing emergence along the other face as shown in the figure. Find the refractive index of this liquid.



Ans : **Main 2014**

Light ray incident normally on face AB passes without deviation and strikes the face AC at point R at an



$$1.45\times\sin 60^\circ = \mu_{\text{liquid}}\sin 90^\circ$$

$$1.45\times 0.866 = \mu_{\text{liquid}}$$

$$\mu_{\text{liquid}} = 1.256$$

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$$\delta_m = \frac{3A}{2} - A = \frac{A}{2}$$

$$\mu = \frac{\sin\left(\frac{A+\frac{A}{2}}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

$$\mu = \frac{\sin\frac{3A}{4}}{\sin\frac{A}{2}} = \frac{\sin 45^\circ}{\sin 30^\circ}$$

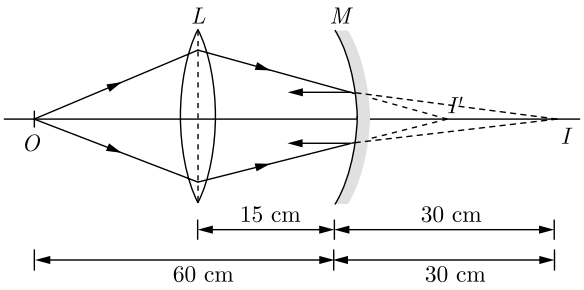
$$= \frac{0.7071}{0.5} = 1.414$$

$$v = \frac{c}{\mu} = \frac{3\times10^8}{1.414}$$

$$= 2.121\times10^8 \text{ m/s}$$

331. A convex lens of focal length 20 cm is placed coaxially with a convex mirror of radius of curvature 20 cm. The two are kept at 15 cm from each other. A point object lies 60 cm in front of the convex lens. Draw a ray diagram to show the formation of the image by the combination. Determine the nature and position of the image formed.

Ans : **Main 2017, 2014**



For convex lens, $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$

$$f = +20 \text{ cm}$$

$$u = -60 \text{ cm}$$

$$\frac{1}{+20} = \frac{1}{v} - \frac{1}{-60}$$

$$\frac{1}{v} = \frac{1}{20} - \frac{1}{60} = \frac{1}{30}$$

$$v = +30 \text{ cm}$$

On the absence of the mirror, the lens would formed be image of I' Which acts as a virtual object for the convex mirror.

f_2 = distance of virtual object I' from mirror

$$= +30 \text{ cm} - 15 \text{ cm}$$

$$= +15 \text{ cm}$$

$$f_m = \frac{R}{2} = \frac{+20}{2} = +10 \text{ cm}$$

From mirror formula,

$$\frac{1}{f_m} = \frac{1}{v_2} + \frac{1}{u_2}$$

$$\frac{1}{f_m} = \frac{1}{v_2} + \frac{1}{15}$$

$$\frac{1}{v_2} = \frac{1}{10} - \frac{1}{15} = \frac{1}{30}$$

$$v_2 = +30 \text{ cm}$$

Hence, the final image I is a virtual image formed at a distance of 30 cm to the right of convex mirror or 45 cm from the convex lens.

332. A compound microscope has $f_0 = 2$ m and $f_e = 5$ cm, the distance between the two lenses $d = 15$ cm. Locate the position of placement of object in front of objective so that final image formed by the compound microscope is (1) at least distance of distinct vision $D = 25$ cm (2) at infinity. Also evaluate the magnification in each case.

Ans : **Main 2011**

Focal length of objective,

$$f_0 = 2 \text{ m} = 200 \text{ cm}$$

Focal length of eyepiece,

$$f_e = 5 \text{ cm}$$

The distance between the lens,

$$d = 15 \text{ cm}$$

1. When the final image formed at least distance of distant vision.

$$m = \frac{v_0}{u_0}\left(1 + \frac{D}{f_e}\right)$$

Image distance for objective,

v_0 = Tube length or distance between lens

$$v_0 = 15 - 5 = 10 \text{ cm}$$

Using Cartesian sign convention for the objective

$$v_0 = 10 \text{ cm}$$

$$f_0 = 2 \text{ cm}$$

$$\frac{1}{u_0} = \frac{1}{v_0} - \frac{1}{f_0} = \frac{1}{10} - \frac{1}{2}$$

$$= \frac{1-5}{10} = \frac{-4}{10}$$

$$u_0 = \frac{-10}{4} = \frac{-5}{2} \text{ cm}$$

Now, $m = \frac{10}{-5} \times 2\left(1 + \frac{25}{5}\right)$

$$m = -4(1+5)$$

$$m = -24 \text{ or } 24 \text{ (Numerically)}$$

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$$\frac{1}{f} = (1.5-1)\left(\frac{1}{15}-\frac{1}{\infty}\right)$$
$$= \frac{0.5}{15} = \frac{1}{30}$$
$$f = 30\text{ cm}$$

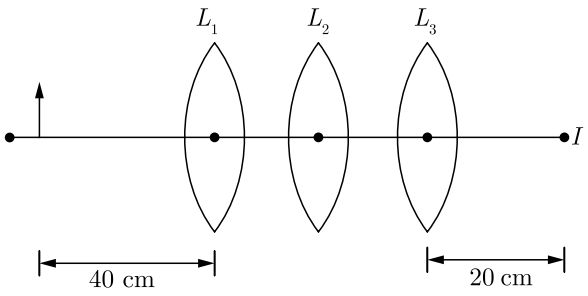
Focal length of piano-concave lens is,

$$\frac{1}{f} = (1.5-1)\left(\frac{1}{\infty}-\frac{1}{15}\right)$$
$$= \frac{-0.5}{15} = -\frac{1}{30}$$
$$f = -30\text{ cm}$$

Since, parallel beams are incident on the lens, its image from plano-concave lens will be formed at +20 cm from it (at the focus) and will act as an object for piano-concave lens. Since, the two lens are at a distance of 20 cm from each other, therefore, for the next lens.

$$u = +20\text{ cm}$$
$$v = \frac{uf}{u+f} = \frac{20\times -30}{20-30}$$
$$= \frac{-600}{-10} = 60\text{ cm}$$

324. You are given three lenses L_1, L_2 and L_3 each of focal length 20 cm. An object is kept at 40 cm in front of L_1, as shown in figure. The final real image is formed at the focus I of L_3, Find the separations between L_1, L_2 and L_3.



Ans : SQP 2012

Given, $f_1 = f_2 = f_3 = 20\text{ cm}$

For lens L_1, $u_1 = -40\text{ cm}$

By lens formula,

$$\frac{1}{v_1}-\frac{1}{u_1} = \frac{1}{f_1}$$
$$\frac{1}{v_1} = \frac{1}{20}-\frac{1}{-40}$$
$$v_1 = 40\text{ cm}$$

For lens L_1, $f_3 = 20\text{ cm}$, $v_3 = 20\text{ cm}$, $u_3 = ?$

By lens formula,

$$\frac{1}{v_3}-\frac{1}{u_3} = \frac{1}{f_3}$$
$$\frac{1}{20}-\frac{1}{u_3} = \frac{1}{20}$$
$$\frac{1}{u_3} = 0$$
$$u_3 = \infty$$

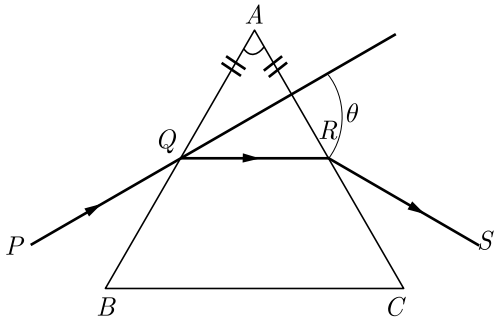
Thus lens L_2 should produce image at infinity.

Hence, for L_2, it's objective should be at focus. The image formed by lens L_1 is at 40 cm on the right side of lens L_1. Which lies at 20 cm left of lens L_2, i.e., focus of lens L_2.

Hence, the distance by lens L_2 lies at infinity, then the distance between lens L_2 and L_3 does not matter.

Hence, the distance between L_2 and L_3 can have any value.

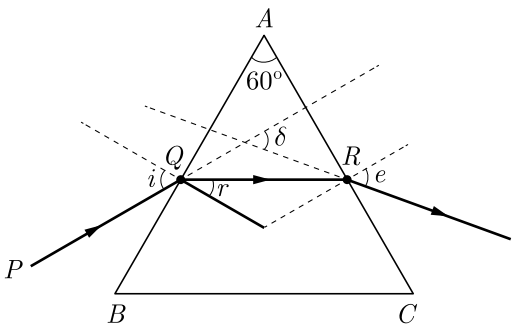
325. A ray PQ incident on the refracting face BA is refracted in the prism BAC as shown in the figure and emerges from the other refracting face AC as RS such that $AQ = AR$. If angle of prism $A = 60^\circ$ and refractive index of material of prism is $\sqrt{3}$, calculate angle θ.



Ans : SQP 2016

Given, $AQ = AR$

We have, $QR \parallel BC$



At the minimum deviation, the refracted ray inside the prism becomes parallel to its base.

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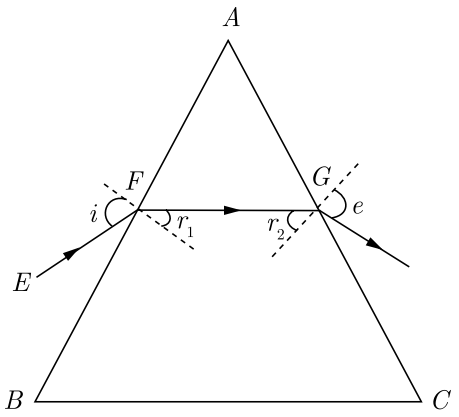
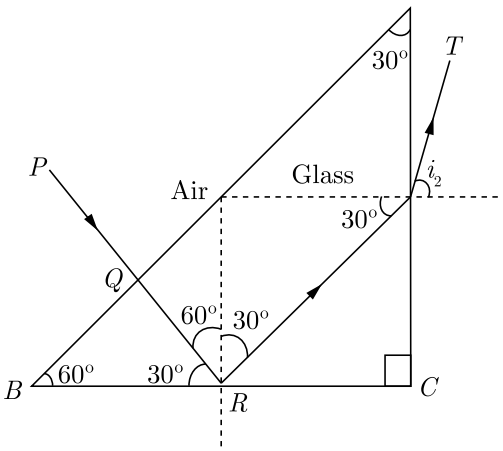


Ans : **Main 2007**

Consider the diagram in which ray of light P, strikes at 90°, it goes undeviated and then it strikes on the face BC at an angle of incidence 60°, which is greater than the critical angle for the glass-air surface.

Hence, on the surface BC, total internal reflection of light will take place. Totally, internally reflected ray, then strikes on the face AC at S, at the angle of incidence 30°, where the refraction of light will take place such that i_2 will be final angle of emergence.

Using Snell's law, $\dfrac{\sin 30^\circ}{\sin i_2} = {}_g\propto_a = \dfrac{1}{{}_a\propto_g}$

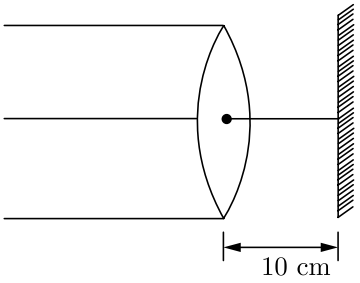


Hence, $\sin i_2 = \sin 30^\circ \times {}_a\mu_g$

$\sin i_2 = \dfrac{1}{2} \times 1.5 = 0.75 = \dfrac{3}{4}$

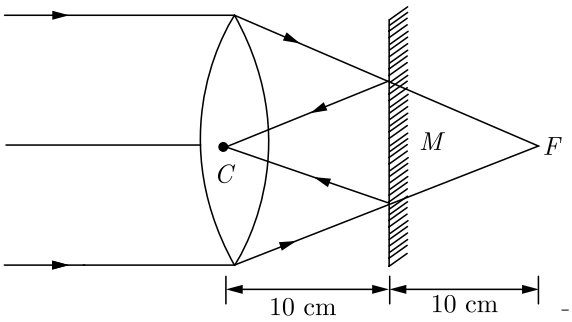
317. A convex lens and a plane minor are kept at a distance of 10 cm as shown in the diagram below. Parallel rays incident on the convex lens after reflection from the mirror form an image at the optical centre.

Complete the ray diagram and find out the focal length of the lens.



Ans : **Main 2005**

Consider the ray diagram shown, parallel rays after refraction through the lens converge towards the point F, which is the focus of the lens.



The refracted rays after reflection from the plane mirror placed in the path meet at the optical centre C of lens.

Thus, C is the image of the virtual point object F formed by the plane mirror.

Hence, $MF = MC = 10\,\text{cm}$

The focal length of the lens is given by

$f = CF = MC + MF$

$= 10 + 10 = 20\,\text{cm}$

Hence, object should be placed at 30 cm.

318. An object is kept in front of a concave mirror of focal length 15 cm. The image formed is three times the size of the object. Calculate the two possible distances of the object from the mirror.

Ans : **Main 2016**

As the mirror is concave, so

$f = -15\,\text{cm}$

When the image formed is real,

$m = \dfrac{h_2}{h_1} = -\dfrac{v}{u} = -3$

or $v = +3u$

As, $\dfrac{1}{u} + \dfrac{1}{v} = \dfrac{1}{f}$

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328. At what distance an object be placed from a convex lens of focal length 15 cm so that its three times magnified image is formed?

Ans : SQP 2017

Focal length of the lens,

$$f = +15\text{ cm}$$

Magnification, $m = \pm 3$

$$m = \frac{v}{u}$$

$$v = mu = \pm 4u$$

For real image, $v = -3u$

For virtual image, $v = 3u$

1. For virtual image,

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \text{ (lens formula)}$$

$$\frac{1}{15} = \frac{1}{3u} - \frac{1}{u}$$

$$\frac{1}{15} = \frac{1-3}{3u}$$

$$\frac{1}{15} = \frac{-2}{3u}$$

$$u = \frac{-2}{3} \times 15 = -10\text{ cm}$$

2. For real image,

$$v = -3u$$

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

$$\frac{1}{15} = \frac{1}{-3u} - \frac{1}{u}$$

$$\frac{1}{15} = \frac{-1-3}{3u}$$

$$\frac{1}{15} = \frac{-4}{3u}$$

$$u = \frac{-4}{3} \times 15 = -20\text{ cm}$$

329. A convex lens of glass ($\mu = 1.5$) has focal length of 20 cm. The lens is immersed in water of refractive index 1.33. What is the change in the power of convex lens?

Ans : Main 2011

Refractive index of glass with respect to air,

$${}^{a}\mu_g = 1.5$$

Refractive index of water with respect to air,

$${}^{a}\mu_w = 1.33$$

and focal length of convex lens in air,

$$f_a = 20\text{ cm} = 0.2\text{ m}$$

refractive index of glass with respect to water,

$${}^{w}\mu_g = \frac{{}^{a}\alpha_g}{{}^{a}\alpha_w} = \frac{1.5}{1.33} = 1.128$$

We also know that relation for the focal length of convex lens in air f_a is,

$$\frac{1}{f_a} = ({}^{a}\mu_g - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\frac{1}{0.2} = (1.5-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\frac{1}{R_1} - \frac{1}{R_2} = 10$$

Similarly, relation for the focal length of convex lens when immersed in water f_w is,

$$\frac{1}{f_w} = ({}^{w}\mu_g - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$= (1.128-1) \times 10 = 1.28$$

$$f_w = \frac{1}{1.28} = 0.78\text{ m}$$

Therefore power of convex lens in air,

$$P_a = \frac{1}{f_a} = \frac{1}{0.2} = 5\text{ D}$$

and power of convex lens when immersed in water,

$$P_w = \frac{1}{f_w} = \frac{1}{0.78} = 1.28\text{ D}$$

Therefore change in power of convex lens

$$= P_a - P_w$$

$$= 5\text{ D} - 1.28\text{ D} = 3.72\text{ D}$$

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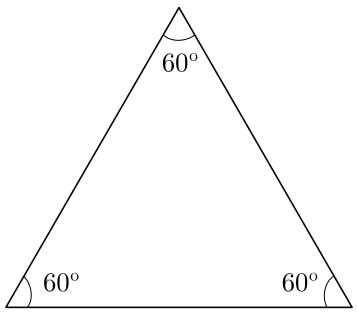
330. A ray of light passing from air through an equilateral glass prism undergoes minimum deviation when the angle of incidence is 3/4th of the angle of prism. Calculate the speed of light in the prism.

Ans : Main 2024, 2018

For equilateral prism, $A = 60^\circ$

For minimum angle of deviation



$$i + e = A + \delta_m$$

$$2i = A + \delta_m$$

$$2 \times \frac{3A}{4} = A + \delta_m$$

Hence, θ the angle of minimum deviation

$$\mu = \frac{\sin\left(\frac{A+\theta}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

$$\sqrt{3} = \frac{\sin\left(\frac{60^\circ+\theta}{2}\right)}{\sin 30^\circ}$$

$$\sin\left(\frac{60^\circ+\theta}{2}\right) = \frac{\sqrt{3}}{2}$$

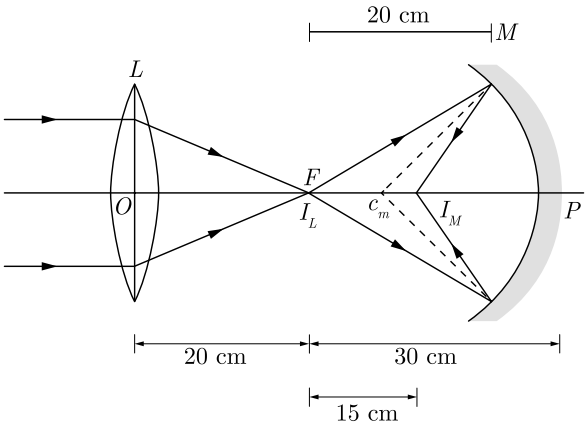
$$\sin\left(\frac{60^\circ+\theta}{2}\right) = \sin 60^\circ$$

$$\frac{60^\circ+\theta}{2} = 60^\circ$$

$$\theta = 60^\circ$$

326. A convex lens of focal length 20 cm is placed coaxially with a concave mirror of focal length 10 cm at a distance of 50 cm apart from each other. A beam of light coming parallel to the principal axis is incident on the convex lens. Find the position of the final image formed by this combination. Draw the ray diagram showing the formation of the image.

Ans : SQP 2014



For the convex lens,

$$u = \infty,\ f = 20\,\text{cm}$$

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

Hence, $v = 20\,\text{cm}$

For the convex mirror, the image formed by the lens acts as the object.

Hence, $u = -(50-20)\ \text{cm}$

$= -30\ \text{cm}$ and $f = -10\ \text{cm}$

Using mirror formula, we get

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$

$$\frac{1}{u} + \frac{1}{-30} = \frac{1}{-10}$$

$$\frac{1}{v} = \frac{1}{30} - \frac{1}{10} = -\frac{1}{15}$$

$$v = -15\,\text{cm}$$

The lens mirror combination, therefore, forms a real image I_2 at a distance of 15 cm to the concave mirror or at a distance of 35 cm to the right of convex lens.

327. Two convex lenses of focal length 20 cm and 1 cm constitute a telescope is focused on a point which is 1 m away from the objective. Calculate the magnification produced and the length of the tube if the final image is formed at a distance 25 cm from the eyepiece.

Ans : SQP 2011

Given, $f_0 = 20\,\text{cm},\ f_e = 1\,\text{cm},$

$v_e = -25\,\text{cm}$

and $u_0 = 1\,\text{m} = 100\,\text{cm}$

For objective

$$u_0 = 1\,\text{m} = 100\,\text{cm}$$

$$\frac{1}{f_0} = \frac{1}{v_0} - \frac{1}{u_0} = \frac{1}{20}$$

$$= \frac{1}{v_0} - \frac{1}{(-100)}$$

$$\frac{1}{v_0} = \frac{1}{20} - \frac{1}{100} = \frac{5-1}{100} = \frac{4}{100}$$

$$v_0 = 25\,\text{cm}$$

For eye piece

$$f_e = 1\,\text{cm},\ u_e = ?,\ v_e = -25\,\text{cm}$$

$$\frac{1}{f_e} = \frac{1}{u_e} = \frac{25}{25} = -\frac{1}{u_e}$$

$$1 + \frac{1}{25} = -\frac{1}{u_e} = \frac{25}{26} = -\frac{1}{u_e}$$

$$u_e = -\frac{25}{26}$$

$$|u_e| = -0.96\,\text{cm}$$

Magnification, $m = -\frac{v_0}{u_0}\left(1 + \frac{D}{f_e}\right)$

$$= -\left(\frac{25}{100}\right)\left(1 + \frac{25}{1}\right)$$

$$m = -\frac{1}{4} \times 26$$

$$= -6.5$$

Length of telescope,

$$L = v_0 + u_e$$

$$= 25 + 0.96$$

$$L = 25.96\,\text{cm}$$

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2. When the final image is formed at infinity. The magnifying power of the microscope will be,

$$m = \frac{v_0}{u_0} \times \frac{D}{f_e}$$
$$= \frac{10}{-5} \times 2 \times \frac{25}{5}$$
$$= -20 \text{ or } 20 \text{ (Numerically)}$$

333. A convex lens of focal length 25 cm is placed coaxially in contact with a concave lens of focal length 20 cm. Determine the power of the combination. Will the system be converging or diverging in nature?

Ans : **Main 2016, 2014**

focal length of convex lens,

$$f_1 = +25 \text{ cm} = +0.25 \text{ m}$$

Focal length of concave lens,

$$f_2 = -20 \text{ cm} = -0.20 \text{ m}$$

Equivalent focal length of convex and concave lens,

$$F = \frac{1}{f_1} + \frac{1}{f_2}$$
$$= \frac{1}{25} + \frac{1}{-20} = -\frac{1}{100}$$

Hence, $F = -100 \text{ cm} = -1 \text{ m}$

Now, the power of lens,

$$P = \frac{1}{f}$$

For convex lens, $P_2 = \frac{1}{f_1} = \frac{1}{0.25}$

For concave lens, $P_2 = \frac{1}{f_2} = \frac{1}{-0.20.}$

Hence, power of the combination

$$P = P_1 + P_2$$
$$= \frac{1}{0.25} + \frac{1}{-0.20}$$
$$= \frac{100}{25} + \frac{100}{-20}$$
$$= \frac{400 - 500}{100}$$
$$= \frac{-100}{100} = -1\text{D}$$

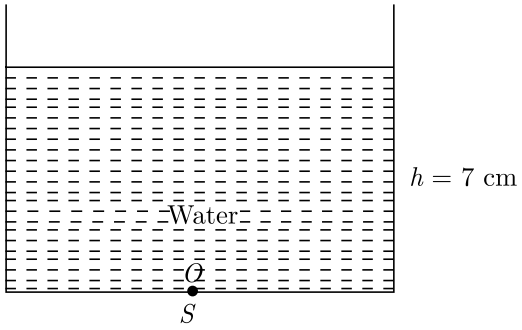
Here, the focal length of the combination

$$= 100 \text{ cm} = -1\text{m}$$

Since, the focal length is in negative, so the system will be diverging in nature.

334. A point source of monochromatic light S is kept at the centre C of the bottom of a cylinder. The radius of the circular base of the cylinder is 15.0 cm.

The cylinder contains water (refractive index = 4/3) to a height of 7.0 cm as shown in the figure. Find the area surface through which light emerges in air. (Take, $\pi = 22/7$)



Ans : **Main 2009, 2007**

We have to use the concept of critical angle and the area of the circle will be confined within the two totally reflecting points.

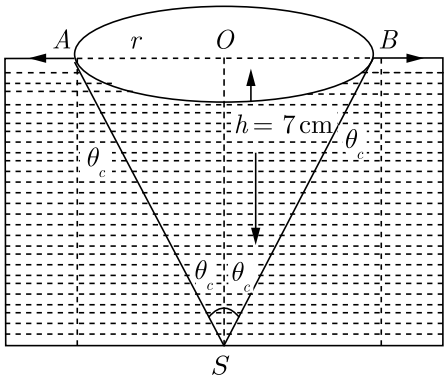
According to the question,

Given, $h = 7 \text{ cm}$,

$$\frac{\alpha_w}{\alpha_a} = {}_a\mu_w = \frac{4}{3}$$

We can write $\sin\theta_c = \frac{1}{{}_a\mu_w} = \frac{3}{4} = 0.75$

$$\theta_c = \sin^{-1}0.75 = 48.6^\circ$$



Now, $\tan\theta_c = \frac{\text{Perpendicular}}{\text{Base}} = \frac{r}{h}$

$$r = h\tan\theta_c = 7 \times \tan 48.6^\circ$$
$$r = 7.94 \text{ cm (approx)}$$
$$\text{Area} = \pi r^2 = \frac{22}{7} \times (7.94)^2$$
$$= 198 \text{ cm}^2$$

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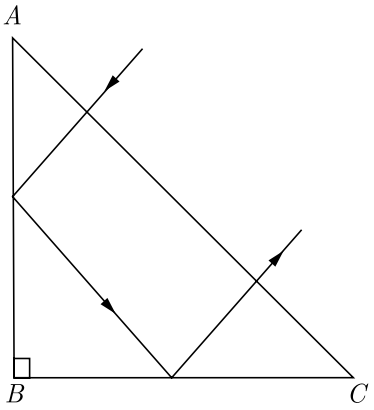
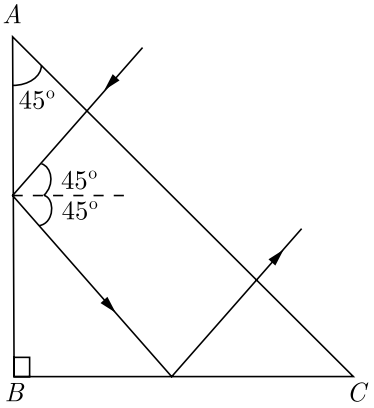
321. A ray of light falls on a right angled prism ABC ($AB = BC$) and travels as shown in the figure. What is the refractive index of the material of the prism ?



Ans : **Main 2006**

For the ray incident on the face,



As there is total internal reflection takes place at AB. Angle of incidence $i >$ Critical angle i_c

In this case $i > i_c,\ \mu = \text{cosec}\, i_c$

Where, $\mu =$ refractive index of prism

$$\mu > \text{cosec}\, 45^\circ \Rightarrow \mu > \sqrt{2}$$

322. Radius of curvature of an equi-convex lens of glass ($n = 1.5$) is 30 cm. Find its focal length. An object of height 5.0 cm is placed at a distance of 60 cm from the optical centre of the lens. Find the position and the height of the image formed.

Ans : **Main 2022 Sem-II**

Given, $n = 1.5,\ R_1 = +30\,\text{cm},$

$R_2 = -30\,\text{cm}\ \ u = -60\,\text{cm}$

Using lens maker's formula,

$$\frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

$$\frac{1}{f} = (1.5-1)\left[\frac{1}{30} + \frac{1}{30}\right]$$

$$\frac{1}{f} = \frac{0.5 \times 2}{30}$$

$$\frac{1}{f} = \frac{1}{30}$$

$$f = 30\,\text{cm}$$

Linear magnification,

$$m = \frac{f}{f+u}$$

$$m = \frac{30}{30-60}$$

$$m = -1$$

and $$m = \frac{v}{u}$$

$$-1 = \frac{v}{-60}$$

$$v = 60\,\text{cm}$$

Image will be formed at 60 cm from lens.

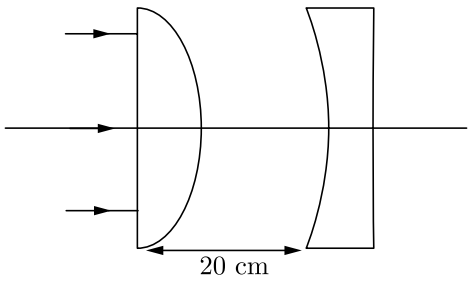
Also, $$m = \frac{\text{height of image}}{\text{height of object}}$$

$$-1 = \frac{\text{height of image}}{5}$$

$$\text{height of image} = -5\,\text{cm}$$

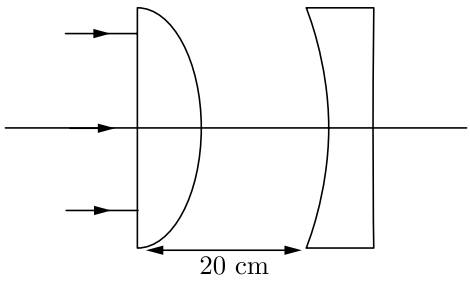
Negative sign indicate that the image is inverted.

323. In the given figure the radius of curvature of curved face in the piano-convex and the plano-convace lens is 15 cm each. The refractive index of the material of the lenses is 1.5. Find the final position of the image formed.



Ans : **Main 2023**

Focal length of plano-convex lens is :



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$$\frac{1}{f} = \frac{1}{y} - \frac{1}{(-x)}$$

$$\frac{1}{f} = \frac{1}{y} + \frac{1}{x} \quad ...(1)$$

For second position of lens, we have

$$\frac{1}{f} = \frac{1}{y-20} - \frac{1}{[-(x+20)]}$$

$$\frac{1}{f} = \frac{1}{y-20} + \frac{1}{x+20} \quad ...(2)$$

From eq (1) and eq (2), we have

$$\frac{1}{y} + \frac{1}{x} = \frac{1}{(y-20)} + \frac{1}{(x+20)}$$

$$\frac{x+y}{xy} = \frac{(x+20)+(y-20)}{(y-20)(x+20)}$$

$$\frac{x+y}{xy} = \frac{x+y}{(y-20)(x+20)}$$

Hence, $xy = (y-20)(x+20)$

$$xy = xy - 20x + 20y - 400$$

$$20x - 20y = -400$$

Hence, $x - y = -20$

Also, $x + y = 100$

On solving, we have,

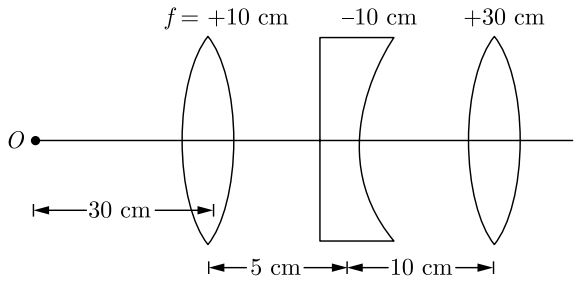
$$x = 40\,\text{cm}$$

and $y = 60\,\text{cm}$

Hence, $\frac{1}{f} = \frac{1}{60} - \frac{1}{-40} = \frac{5}{120}$

Hence, $f = 24\,\text{cm}$

338. Find the position of the image formed of an object O by the lens combination given in the figure.



Ans : SQP 2014, 2012

For first lens, $u_1 = -30\,\text{cm}$, $f_1 = +10\,\text{cm}$

Hence lens formula,

$$\frac{f}{f_1} = \frac{1}{v_1} - \frac{1}{u_2}$$

$$\frac{1}{v_1} = \frac{1}{f_1} + \frac{1}{u_1}$$

$$= \frac{1}{10} - \frac{1}{30} = \frac{3-1}{30}$$

$$v_1 = 15\,\text{cm}$$

This means that the image formed by first is at a distance of 15 cm to the right of first lens. This image serves as a virtual object for second lens.

For second lend, $f_2 = -10\,\text{cm}$,

$u_2 = 15 - 5 = +10\,\text{cm}$

Hence, $\frac{1}{v_2} = \frac{f}{f_2} + \frac{1}{u_2} = -\frac{1}{10} + \frac{1}{10}$

$v_2 = \infty$

This means that the real image is formed by second lens at infinite distance. This acts as an object for third lens.

For third lens, $f_3 = +30\,\text{cm}$, $u_3 = \infty$

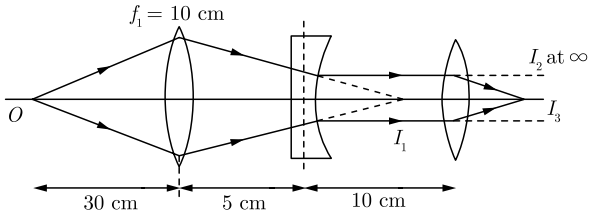
From lend formula,

$$\frac{1}{v_3} = \frac{1}{f_3} + \frac{1}{u_3} = \frac{1}{30} + \frac{1}{\infty}$$

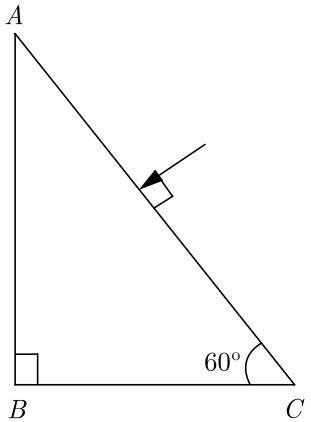
$v_3 = 30\,\text{cm}$

i.e., final image is formed at a distance 30 cm to the right of third lens.

The ray diagram of formation of image is shown in figure.



339. Trace the path of a ray of light passing through a glass prism ABC as shown in the figure. If the refractive index of glass is $\sqrt{3}$, then find out the value of the angle of emergence from the prism.



NODIA

351. Optical instruments are of great utility. They help us in studying very tiny objects as well as very large heavenly bodies. Scientists have developed microscopes like electron microscopes which aid in studying tiny molecules of matter. They have also devised giant telescopes like Hubble telescope and James Web Space telescope which have enabled us to view distant galaxies hitherto unknown.

(i) Which optical instrument is used to study detailed structure of a virus?

(ii) What is the ability of an instrument to form an enlarged image of an object called?

(iii) Hubble telescope orbits around the earth like a satellite. What is the advantage of such a telescope over a similar one on earth's surface?

(iv) An astronomical telescope consists of two convex lenses having focal length of 200 cm and 4 cm. When it forms final image at infinity, calculate its

(a) magnifying power (b) length.

Ans : **Main SQP 2023**

(i) Electron microscopes (move specifically scanning electrode and transmitting electron microscope) are used to study detailed structure of a virus.

(ii) Magnification is the ability of an instrument to form an enlarged image of an object.

(iii) Hubble telescope (space telescopes) have the advantage of being above the blurring effects of the earth's atmosphere. In addition, there are many wavelengths from the electromagnetic spectrum do not reach earth because they are absorbed or reflected by the earth's atmosphere.

(iv) (a) Magnifying power

$$(m) = \frac{-f_o}{f_e}$$

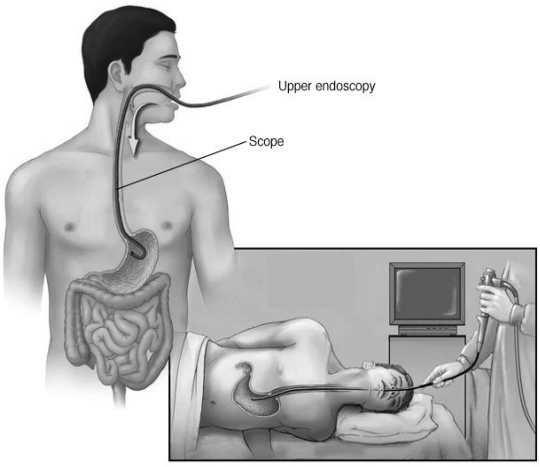
$$= -\frac{200\text{ cm}}{4\text{ cm}} = -50$$

(b) Length of telescope

$$(L) = f_o + f_e$$

$$= 200 + 4 = 204\text{ cm}$$

352. One day Chetan's mother developed a severe Stomach ache all of a sudden. She was rushed to the doctor who suggested for an immediate endoscopy test and gave an estimate of expenditure for the same. Chetan immediate contacted his class teacher and shared the information with her. The class teacher arranged for the money and rushed to the hospital. On tantalising that Chetan belonged to a below average income group family, even the doctor offered concession for the test. The test was conducted successfully.



(a) Which principal in optics is used in endoscopy? Explain this principal briefly.

(b) Briefly explain the values reflected in the action asked by the teacher.

Ans :

(a) Total internal reflection. If a light ray enters at one end of an optic fibre coated with a material of low refractive index, it is refracted and strikes the walls at an angle greater than the critical angle.

(b) The teacher knows that Chetan belongs to a below Average income group family, So he/she immediately Arranged the money required to be paid as test fee. His/her caring and helping attitude towards others resulted in timely help to Chetan's mother.

Such helping attitude on the part of the person living in the society makes it a better society to live in.

353. Now-a-days optical fibres are extensively used for transmitting audio and video signals through long distances. Optical fibres too make use of the phenomenon of total internal reflection. Optical fibres are fabricated with high quality composite glass/quartz fibres. Each fibre consists of a core and cladding. The refractive index of the material of the core is higher than that of the cladding. When a signal in the form of light is directed at one end of the fibre at a suitable angle, it undergoes repeated total internal reflections along the length

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341. A small telescope has an objective lens of focal length 105 cm and eyepiece of focal length 5 cm. What is the magnifying power of the telescope for viewing distance objects in normal adjustments.

In this telescope is used to view a 100 km tall tower 3 km away, than what is the height of the tower formed by the objective lens.

Ans : **SQP 2012**

When final image is at D, then magnifying power,

$$m = \frac{f_0}{f_e}\left(1+\frac{f_e}{D}\right)$$

In normal adjustment, $m = \frac{-f_0}{f_e}$

For telescope,

Focal length of objective lens,

$$f_0 = 150\text{ cm}$$

Focal length of eye lens, $f_e = 5\text{ cm}$

When final image forms at, $D = 25\text{ cm}$

As we know that,

Magnification, $m = \frac{-f_0}{f_e}\left(1+\frac{f_e}{D}\right)$

$$= \frac{-150}{5}\left(1+\frac{5}{25}\right)$$

$$= \frac{-150}{5}\times\frac{6}{5}$$

$$m = -36$$

Let height of final image be h cm.

$$\tan\beta = \frac{h}{25}$$

$\beta =$ visual angle formed by final image at eye.

$\alpha =$ visual angle subtended by object at objective.

$$\tan\alpha = \frac{100\text{ m}}{3000\text{ m}} = \frac{1}{30}$$

But, $m = \frac{\tan\beta}{\tan\alpha}$

$$-36 = \frac{\left(\frac{h}{25}\right)}{\left(\frac{1}{30}\right)}$$

$$-36 = \frac{h}{25}\times 30$$

$$-36 = \frac{6h}{5}$$

$$h = \frac{-36\times 5}{6}$$

$$h = -30\text{ cm}$$

CASE BASED QUESTIONS

342. Mr. Viswanathan, a retired professor of physics was walking with his grandson. It was last week of December and so it was dark around 5.30 pm. The street lights were on and the yellow light flooded the area around. The boy asked professor why yellow lights were used when white light were brighter. The professor answered that during foggy days the tiny droplets act as prisms splitting the white light into its constituent colours and thus reducing the clarity.

(i) What phenomenon was the professor referring to ? Why does it happen ?

(ii) Give one application of prism.

Ans :

(i) Dispersion. Because the speed of each colour is different when the colours enter the glass.

(ii) Studying and analysing the spectrum of distant light sources.

343. Ravi goes to visit a museum. A special mirror is lying there. When he stands in front of the mirror he finds his image having a very small head, a fat body and legs of normal size. He becomes frightened and comes to his friend Shiva to know the facts. Being a science student Shiva explains the reason behind it.

(i) Name the kinds of mirror.

(ii) How do you explain such a thing properly ?

Ans :

(i) Plane, concave and convex mirrors.

(ii) The special mirror is the combination of three mirrors which show their characteristics property.

(a) Convex mirror is the upper portion of the mirror.

(b) Concave mirror is the middle portion of the mirror.

(c) Plane mirror is the lower portion of the mirror.

344. Nisha was working on a physics project. In this she had to construct a good astronomical telescope, while three lenses of power 0.5 D, 4 D, and 10 D are available for her project. She was not sure as to which lenses would she use for constructing such telescope. So she consulted her friend Rani for her problem. Rani explained details and significance of a telescope, which helped Nisha to choose the lenses for her project.

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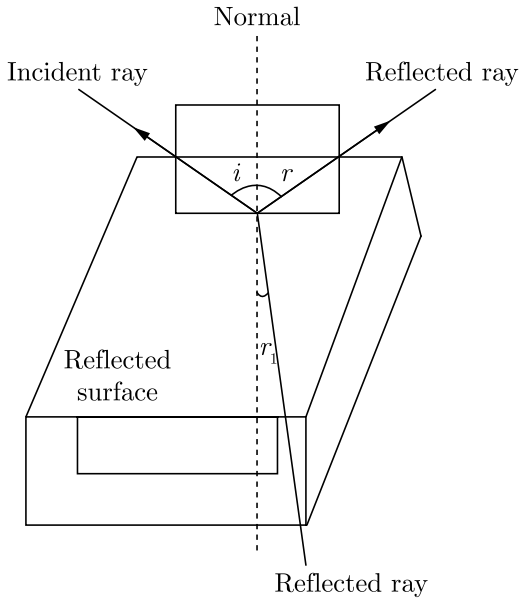
Ans :

1. Speed of light in vacuum/speed of light in medium.
2. 1.8×10^8 m/s.
3. Real depth/Apparent depth.
4. $n = 1/\sin i_c$

355. Refraction involves change in the path of light due to change in the medium.



When a beam of light encounters another transparent medium, a part of light gets reflected back into the first medium, while the rest enters the other. The direction of propagation of an obliquely incident ray of light, that enters the other medium, changes at the interface of two media. This phenomenon is called refraction of light.

(i) For the same value of angle of incidence, the angles of refraction in three media A, B and C are 15°, 25° and 35°, respectively. In which medium, would the velocity of light be minimum?

(ii) Why does a crack in a glass window pane appear silvery?

(iii) The refractive index of diamond is much higher than that of glass. How does a diamond cutter make use of this fact?

(iv) What is the apparent position of an object below a rectangular block of glass 6 cm thick, if a layer of water 4 cm thick is on the top of the glass?
(Take, $\mu_{ga} = \frac{3}{2}$ and $\mu_{wa} = \frac{4}{3}$)

Ans :

(i) As refractive index of medium

$$\frac{\text{Velocity of light in vacuum}}{\text{Velocity of light in a medium}} = \frac{\sin i}{\sin r}$$

The medium with angle 15° will have the highest refractive index and hence the velocity of light will be minimum.

(ii) Because of the presence of air in the crack, which results in total internal reflection.

(iii) The refractive index of diamond is more than that of ordinary glass. The critical angle for diamond is less than that for glass. A diamond is cutter uses a large angle of incidence to ensure that the light entering the diamond is totally reflected from its faces so that the diamond sparkles.

(iv) Real depth of glass, $x_1 = 6$ cm

Real depth of water, $x_2 = 4$ cm

$$g_{\mu a} = \frac{3}{2},\ w_{\mu a} = \frac{4}{3}$$

if y_1, y_2 are corresponding depths,

then, $$\frac{x_1}{y_1} = g_{\mu a} = \frac{3}{2}$$

$$y_1 = \frac{2}{3}x_1 = \frac{2}{3} \times 6 = 4 \text{ cm}$$

$$\frac{x_2}{y_2} = w_{la} = \frac{4}{3}$$

$$y_2 = \frac{3}{4}x_2 = \frac{3}{4} \times 4 = 3 \text{ cm}$$

Apparent position of the object

$$= (y_1 + y_2) = (4 + 3) \text{ cm} = 7 \text{ cm}$$

Rise in position of the object.

$$= (x_1 + x_2) - (y_1 + y_2)$$
$$= (6 + 4) - (4 + 3)$$
$$= 10 - 7 = 3 \text{ cm}$$

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348. School arrange an educational trip to Kavalur in Tamil Nadu where an observatory having India largest telescope. On hearing this, the whole class got excited and left for their way to kavalur. In the observatory, the physics teacher was explaining about the type of telescope, with diameter of objective (2.34 m) and several other details. Everyone was ready to look through the telescope.

(i) What type of telescope is the teacher referring to ?

(ii) Mention any two advantages of this telescope.

Ans :

(i) Reflecting telescope.

(ii) No chromatic aberration, mirrors are relatively lighter and cheaper compared to the lens.

349. While driving his car, Rahul suddenly heard loud sound coming from behind. He happened to look through his rear view mirror and saw that an ambulance is approaching. He recollect that mostly emergency vehicles have their names written in mirror script. He quickly give the way for the ambulance murmuring a prayer for fast recovery of patient who is inside the ambulance.

(a) What type of mirror is as a rear-view mirror and why ?

(b) What values did Rahul exhibit ?

Ans :

(a) Convex mirror, to get a wide view of traffic behind.

(b) Compassion, courtesy, concern for others, and knowledgeable.

350. A glass window has been broken into tiny particles of glass in a robbery case. Some of there tiny Particles are found at the scene of crime and some in the robbers clothing If the police can both particles found from the places are similar. They have a strong case. Being a responsible person Deepak helped the police to prove such case.

(a) Which phenomenon is responsible for proving Such case?

(b) How do you prove such case?

(c) What do you mean by refraction of light?

Ans :

(a) Refraction

(b) Suspend the particles of glass in a special liquid and particles are viewed through a microscope. Change the temperature or liquid slowly. At a certain temperature particles of glass disappear. Then they probably came from the same broken pane of glass. In this case refractive index of liquid becomes equal to the refractive index of particles of glass.

(c) Refraction of light is the change in the direction of light as it passes from one medium to another.

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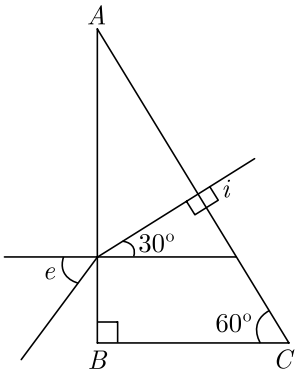
Ans : **Main 2018, 2013**

Refractive index of glass, $u_g = \sqrt{3}$

Since, $i = 0$



At the interface AC, we have (according to Snell's law)

$$\frac{\sin i}{\sin r} = \frac{\mu_g}{\mu_a}$$

But, $\sin i = \sin 0^\circ = 0$

Thus, $\sin r = \frac{\alpha_a \sin i}{\alpha_g} = 0$

Hence, $r = 0$

This ray pass unrefracted at AC interface and reaches AB interface. Here, we can see angle of incidence becomes 30°. Thus, applying Snell's law,

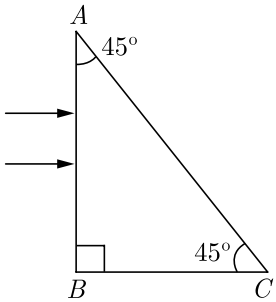
$$\frac{\sin 30^\circ}{\sin e} = \frac{\mu_g}{\mu_a} = \frac{1}{\sqrt{3}}$$

$$\sin e = \sqrt{3} \times \sin 30^\circ = \frac{\sqrt{3}}{2}$$

Thus, $e = 60^\circ$

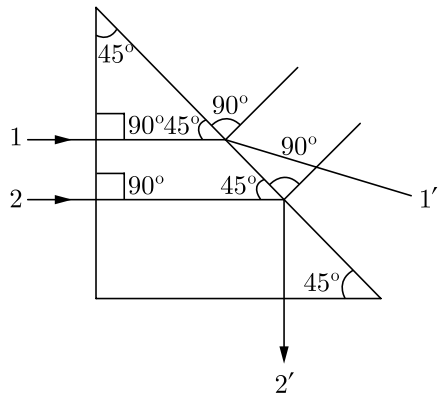
Hence, angle of emergence is 60°.

340. Two monochromatic rays of light are incident normally on the face AB of an isosceles right-angled prism ABC. The refractive indices of the glass prism for the two rays 1 and 2 are respectively 1.35 and 1.45. Trace the path of these rays after entering through the prism.



Ans : **SQP 2010**

The paths are shown as below



From the figure, it is clear that angle of incidence for ray 1 is 45°.

For ray 1, $\sin i = \sin 45^\circ$

$$= \frac{1}{\sqrt{2}} = \frac{1}{1.414}$$

For ray 1, refractive index of the prism is $\mu = 1.35$

$$\mu = \frac{1}{\sin C}$$

$$\sin C = \frac{1}{\mu} = \frac{1}{1.35}$$

Here, $\frac{1}{1.414} < \frac{1}{1.35}$

i.e., $\sin i < \sin C$

or $i < C$

So, ray 1 will be refracted by the prism.

For ray 2, angle of incidence,

$$i = 45^\circ$$

$$\sin i = \sin 45^\circ$$

$$= \frac{1}{\sqrt{2}} = \frac{1}{1.414}$$

For ray 2, the refractive index, $\mu = 1.45$

$$\mu = \frac{1}{\sin C}$$

$$\sin C = \frac{1}{\mu} = \frac{1}{1.45}$$

Here, $\frac{1}{1.414} > \frac{1}{1.45}$

i.e., $\sin i = \sin C$

or $i > C$

So, ray 2 will get total internally reflected.

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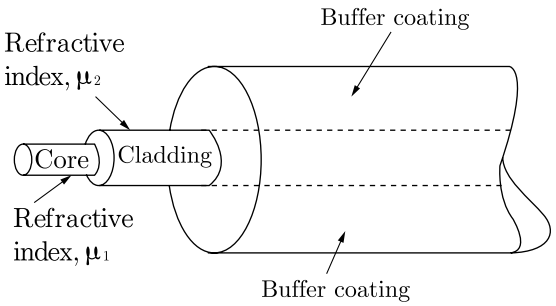
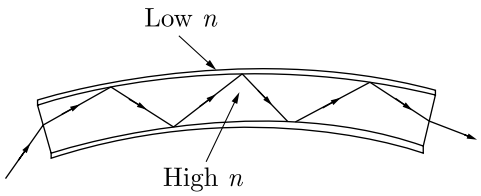
of the fibre and finally comes out at the other end. Since light undergoes total internal reflection at each stage, there is no appreciable loss in the intensity of the light signal. Optical fibres are lubricated such that light reflected at one side of inner surface strikes the other at an angle larger than the critical angle. Even if the fibre is bent, light can easily travel along its length. Thus, an optical fibre can be used to act as an optical pipe.





1. What is the condition for total internal reflection to occur?
2. Which signal is transmitted by optical fibres?
3. What is the internal reflection of light?

Ans :

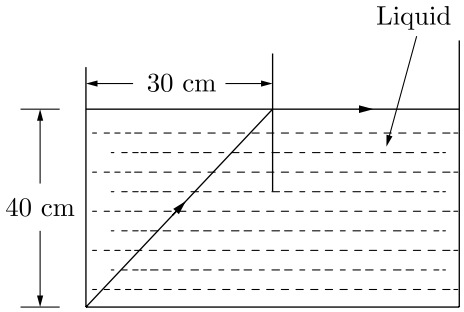
1. Angle of incidence must be greater than the critical angle.
2. Optical Signal.
3. The phenomenon which occurs when the light rays travel from a more optically denser medium to a less optically denser medium.

354. Total internal reflection (TIR) is the optical phenomenon in which waves arriving at the interface (boundary) from one medium to another (e.g., from water to air) are not refracted into the second ("external") medium, but completely reflected back into the first ("internal") medium. It occurs when the second medium has a higher wave speed (i.e., lower refractive index) than the first, and the waves are incident at a sufficiently oblique angle on the interface. For example, the water-to-air surface in a typical fish tank, when viewed obliquely from below, reflects the underwater scene like a mirror with no loss of brightness.

TIR occurs not only with electromagnetic waves such as light and microwaves, but also with other types of waves, including sound and water waves. If the waves are capable of forming a narrow beam , the reflection tends to be described in terms of "rays" rather than waves; in a medium whose properties are independent of direction, such as air, water or glass, the "rays" are perpendicular to the associated wave fronts.

Repeated total internal reflection of a 405nm laser beam between the front and back surfaces of a glass pane. The colour of the laser light itself is deep violet; but its wavelength is short enough to cause fluorescence in the glass, which re-radiates greenish light in all directions, rendering the zigzag beam visible.

Refraction is generally accompanied by partial reflection. When waves are refracted from a medium of lower propagation speed (higher refractive index) to a medium of higher speed e.g., from water to air the angle of refraction (between the outgoing ray and the surface normal) is greater than the angle of incidence (between the incoming ray and the normal). As the angle of incidence approaches a certain threshold, called the critical angle, the angle of refraction approaches 90°, at which the refracted ray becomes parallel to the boundary surface. As the angle of incidence increases beyond the critical angle, the conditions of refraction can no longer be satisfied, so there is no refracted ray, and the partial reflection becomes total. For visible light, the critical angle is about 49° for incidence from water to air, and about 42° for incidence from common glass to air.



1. What is refractive index of a medium? (in terms of speed of light)
2. In the above diagram, calculate the speed of light in the liquid of unknown refractive index?
3 What is refractive index of a medium (in terms of real and apparent depth)?
4 What is the relation between refractive index and critical angle for a medium?

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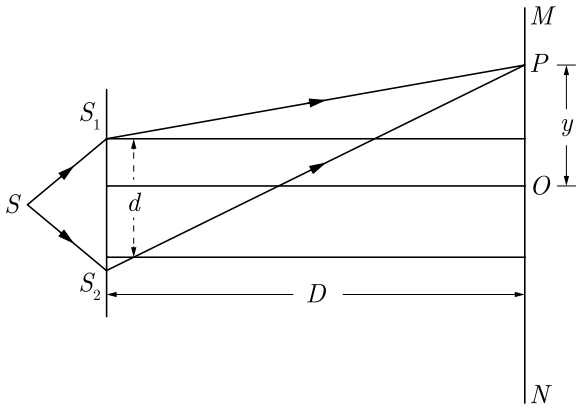
Angular fringe width,

$$\theta = \frac{\beta}{D} = \frac{\lambda}{d}$$

2. Separation of nth order bright fringe from central fringe,

$$Y_n = \frac{Dn\lambda}{d}$$

where, $n = 1, 2, 3, ...$



3. Separation of nth order dark fringe from central fringe,

$$Y_n = (2n-1)\frac{D\lambda}{2d}$$

where, $n = 1, 2, 3 ....$

4. Angular position of nth order,

$$\text{Bright fringe} = \frac{Y_n}{D} = \frac{n\lambda}{d}$$

$$\text{Dark fringe} = \frac{Y_n}{D} = (2n-1)\frac{\lambda}{d}$$

where, $n = 1, 2, 3, ...$

6. INTENSITY OF LIGHT

Intensity of light I is proportional to the width d of slit and ratio of slit-width a.

$$\frac{d_1}{d_2} = \frac{I_2}{I_2} = \frac{a_1^2}{a_2^2}$$

Ratio of maximum and minimum intensity of light,

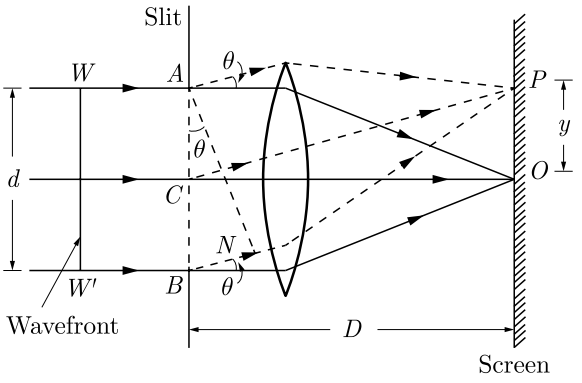
$$\frac{I_{max}}{I_{min}} = \left(\frac{a_1 + a_2}{a_1 - a_2}\right)^2 = \left(\frac{r+1}{r-1}\right)^2$$

where, $r = \frac{a_1}{a_2} = \sqrt{\frac{I_1}{I_2}}$

7. DIFFRACTION DUE TO A SINGLE SLIT

A parallel beam of light with a plane wave-front WW' is made to fall on a single slit AB. Width of the slit is of the order of wavelength of light, therefore, diffraction occurs on passing through the slit.

As shown in the diagram below,



1. n^{th} order secondary minima is obtained when,

$$d\sin\theta = n\lambda$$

where, $r = 1, 2, 3 ...$

2. n^{th} order secondary maximum is obtained when,

$$d\sin\theta = (2n+1)\frac{\lambda}{2}$$

where, $n = 0, 1, 2, 3, ...$

3. Angular separation for n^{th} minima,

$$\theta_n = \frac{n\lambda}{d}$$

where, $n = 0, 1, 2,3, ...$

4. Linear separation of n^{th} secondary minima,

$$Y_n = \frac{Dn\lambda}{d}$$

5. Angular position of n^{th} secondary maxima,

$$\theta_n = (2n+1)\frac{\lambda}{2d}$$

6. Angular width of central maxima $= \frac{2\lambda}{d}$.

7. Linear width of central maxima $= \frac{2D\lambda}{d}$.

8. Angular width of secondary maxima or minima $= \frac{\lambda}{d}$.

9. Linear width of secondary maxima or minima $= \frac{D\lambda}{d}$.

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CHAPTER 10

Wave Optics

SUMMARY

1. HUYGEN'S PRINCIPLE

Huygen's principle is essentially a geometrical construction, which gives the shape of the wavefront at any time, allows us to determine the shape of the wave-front at a later time, According to Huygen's principle:

1. Every point on a wave-front behaves like a light source and emits secondary wavelets.
2. The secondary wavelets spread in all directions in space (vacuum) with the velocity of light.
3. The envelope of wave-front of secondary wavelets, after a given time, along forward direction gives the new position of wave-front.

2. COHERENT SOURCES

Coherent sources of light are the sources which emit light waves of same frequency, same wavelength and have a constant initial phase difference.

Coherent source of light can be obtained by deriving two sources from a primary (or initial) source by,

1. Division of wave-front
2. Division of amplitude

Two such sources of light, which do not emit light waves with a constant phase difference are called incoherent sources.

3. INTERFERENCE OF LIGHT

Interference is the phenomenon of superposition of two light waves of same frequency and constant phase difference travelling in same direction. The position of maximum intensity

are called maxima while those of minimum intensity are called minima.

4. CONDITION OF MAXIMA AND MINIMA

If a_1 and a_2 are amplitudes of interfering waves and θ is the phase difference at a point under consideration, then resultant intensity at a point in the region of superposition

$$I = a_1^2 + a_2^2 + 2a_1a_2\cos\phi$$
$$= I_1 + I_2 + 2\sqrt{I_1I_2}\cos\phi$$

where, $I_1 = a_1^2$ = intensity of one wave

$I_2 = a_2^2$ = intensity of other wave

Condition of Maxima

Phase difference, $\phi = 2n\pi$

Path difference, $\Delta = n\lambda$, n being integer

Maximum amplitude, $A_{max} = a_1 + a_2$

Maximum intensity, $I_{max} = A_{max}^2 = (a_1 + a_2)^2$

$= a_1^2 + a_2^2 + 2a_1a_2$

$= I_1 + I_2 + 2\sqrt{I_1I_2}$

Condition of Minima

Phase difference, $\phi = (2n-1)\pi$

Path difference, $\Delta = (2n-1)\frac{\lambda}{2}$

$n = 1, 2, 3, ...$

Minimum amplitude, $A_{min} = (a_1 - a_2)$

Minimum intensity, $I_{min} = (a_1 - a_2)^2$

$= a_1^2 + a_2^2 - 2a_1a_2$

$= I_1 + I_2 - 2\sqrt{I_1I_2}$

5. YOUNG'S DOUBLE SLIT EXPERIMENT

1. Fringe width of bright and dark fringe,

$$\beta = \frac{D\lambda}{d}$$

where, λ = wavelength of light

D = distance between slit and screen

and d = distance between two slits

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(i) What do you understand by normal adjustment of a telescope ?

(ii) Which lenses will be used as objective and which one as eyepiece from given above lenses?

Ans :

(i) In normal adjustment of telescope, the final image is formed at infinity.

(ii) Out of these three lenses, lens of power 0.5 D will be used for objective while lens of power 10 D as eye piece for construction of such telescope.

345. Ankit goes to visit a museum. A special mirror is lying there. When he stands in front of the mirror he finds his image having a very small head, a fat body and legs of normal size. He becomes frightened and comes to his friend Ramesh to know the facts. Being a science student Ramesh explains the reason behind it.

(a) Name the kinds of mirror.

(b) How do you explain such a thing properly?

Ans :

(a) Plane, concave and convex mirrors.

(b) The special mirror is the combination of three mirrors which show their characteristics properly.

(i) convex mirror is the upper portion of the mirror.

(ii) convex mirror is the middle portion of the mirror.

(iii) Plane mirror is the lower portion of then mirror.

346. Ravi is a student of mechanical engineering studying in one of the engineering colleges. The other day he saw an old man who suddenly collapsed as he walked out of the house in his neighbourhood. Ravi rushed towards him immediately made a call to the nearby hospital, asked for the ambulance and took him to the emergency ward of the hospital. On getting the medical aid, the old man soon got recovered. he did not forget to thank Ravi for the timely help he rendered. He was wondering that in his times to get the telephone connection, one had to wait for years whereas these days it takes no time to get the connection. Ravi told him it was all because of the technological progress/development due to which the simple phenomenon in physics could be easily used.

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(i) To which phenomenon in physics was Ravi referring to, which made the land line links so easily accessible ?

(ii) What are the essential conditions required to observe this phenomenon ?

Ans :

(i) Ravi was referring to the phenomenon of total Internal Reflection

(ii) Conditions required for the occurrence of total internal reflection :

1. Angle of incidence $>$ Critical Angle
2. Light should travel from denser to rarer medium

347. Amit's uncle was finding great difficulty in reading a book placed at normal position. He was not going to the doctor because he could not afford the cost. When Amit came to know of it, he took his uncle to the doctor, After thoroughly checking his eyes, the doctor prescribed the proper lenses for him. Amit bought the spectacles for his uncle from his pocket money. By using spectacles he should now read with great ease, For this, he expressed his gratitude to his nephew. Based on the above paragraph.

(i) Why does the least distance of distinct vision increase with age ?

(ii) What type of lens is required to correct this defect ?

Ans :

(i) The least distance of distinct vision increases with age because of the increase in the minimum possible focal length of the eye lens or contraction of the eye ball.

(ii) This defect can be corrected by placing a convex lens in front of the eye.

OBJECTIVE QUESTIONS

1. Which nature of the wavefront is associated with a parallel beam of light?

(a) plane (b) spherical

(c) cylindrical (d) all of these

Ans : **Main 2008**

We know from the Huygen's wave theory that the locus of all points oscillating in the same phase in a parallel beam of light forms plane wavefront.

Thus (a) is correct option.

2. The inverse square law of intensity (illuminance) is valid for

(a) plane wavefront

(b) conical wavefront

(c) spherical wavefront

(d) cylindrical wavefront

Ans : **SQP 2006**

Inverse square law of intensity (illuminance) is valid for a point source, which produces spherical wavefront.Thus (c) is correct option.

3. The interference occurs in which of the following waves?

(a) transverse (b) longitudinal

(c) electromagnetic (d) all of these

Ans : **SQP 2004**

The phenomenon of non-uniform distribution of energy in a medium, due to superposition of light waves, is called interference of light. It occurs in transverse, longitudinal and electromagnetic waves.

Thus (d) is correct option.

4. What type of wave fronts are associated with a source at infinity?

(a) Cylindrical wave fronts

(b) Plane wave fronts

(c) Spherical wave fronts

(d) All types of wave fronts

Ans : **Main 2023**

When a light source is very far away (at infinity), the curvature of its spherical wavefront becomes very large and appears flat over a small region.

Hence, the rays become nearly parallel, forming a plane wavefront.

Thus (b) is correct option.

5. In Young's double slit experiment, for which colour, fringe width is the least?

(a) green (b) blue

(c) red (d) yellow

Ans : **Main 2010**

Fringe width,

$$\beta = \frac{\lambda D}{d} \propto \lambda$$

Since, wavelength λ of blue colour is least among the given colours, therefore fringe width is least for blue colour.

Thus (b) is correct option.

6. Cylindrical wave fronts are produced by

(a) a point source of light

(b) a line source of light

(c) a source at infinity

(d) all types of sources of light

Ans : **SQP 2023**

A cylindrical wavefront is produced when light originates from a line source. In this case, the light waves spread out in the form of concentric cylinders around the source. A point source produces spherical wavefronts, while a source placed at infinity produces plane wavefronts. Therefore, cylindrical wavefronts are associated with a line source of light.

Thus (b) is correct option.

7. Bright colours exhibited by spider's web exposed to sun light are due to

(a) diffraction (b) polarisation

(c) interference (d) resolution

Ans : **Main 2025**

the phenomenon of non-uniform distribution of energy in a medium, due to superposition of light waves is called interference of light and the bright colours exhibited by the spider's web exposed to sun light is due to this phenomenon.

Thus (c) is correct option.

8. In Huygen's wave theory, the locus of all points oscillating in the same phase is called a

(a) ray (b) vibrator

(c) wavefront (d) half period zone

Ans : **Main 2017**

We know from the Huygen's wave theory that the locus of all points oscillating in the same phase is called a wavefront. In other words, a wavefront is defined as a surface of constant phase.

Thus (c) is correct option.

NODIA

Ans : Main 2014, 2010

Laser light is considered coherent because it consists of light waves having the same wavelength and a constant phase difference. These waves remain perfectly coordinated with one another, producing a highly intense and narrow beam of light.

Thus (d) is correct option.

24. Interference takes place due to change in

(a) velocity (b) intensity

(c) amplitude (d) phase difference

Ans : Main 2007

When two waves of nearly same frequency and same amplitude with zero initial phase difference or constant phase difference superimpose over each other, then non-uniform distribution of energy in the medium is called interference. Therefore interference takes place due to change in phase difference.

Thus (d) is correct option.

25. In Young's double slit experiment, interference was observed, when air was present in the interference chamber. If the chamber is evacuated and the same light is used, then we will see

(a) no interference

(b) interference with dark bands

(c) interference with bright bands

(d) interference with increased fringe width

Ans : Main 2005, 2012

$$\beta = \frac{\lambda D}{d} \propto \lambda$$

Since, refractive index of air is more than that of vacuum, therefore when air is evacuated, then wavelength λ of light increases.

As a result of this, fringe width also increases.

Thus (d) is correct option.

26. In the Young's double slit experiment, the central bright fringe can be identified

(a) as it is wider than bright fringes

(b) as it is narrower than other bright fringes

(c) by using white light instead of monochromatic light

(d) as it has a greater intensity of light than that of other bright fringes

Ans : SQP 2009

In Young's double slit experiment, the central bright fringe can be identified as it has a greater intensity of light than that of the other bright fringes.And width of central bright fringe is equal to other bright and dark fringes.

Thus (d) is correct option.

27. The maximum number of possible interference maxima for slit separation equal to twice the wavelength in Young's double-slit experiment is

(a) zero (b) three

(c) five (d) infinite

Ans : Main 2001

Slit separation, $d = 2\lambda$

We know from the Young's double slit experiment that interference of flight occurs when slit separation

$d =$ less than the wavelength of light used

Since, $d = 2\lambda$

i.e., $d > \lambda$

Therefore no interference occurs.

Thus (a) is correct option.

28. What happens if a monochromatic light used in the Young's double slit experiment is replaced by white light?

(a) no fringes are observed

(b) all bright fringes become white

(c) all bright fringes are coloured between violet and red

(d) only central fringe is white and all other fringes are coloured

Ans : Comp 2024

If white light is used in Young's double slit experiment, we get a central white fringe, because all wavelengths of white light have zero path difference. And all other points on both sides of central white fringe have different path differences for different wavelengths of white light. Therefore no condition of brightness or darkness is satisfied.

As a result of this, coloured fringes are observed on both sides of central white fringe.

Thus (d) is correct option.

29. In Young's experiment, the monochromatic light is used to illuminate two slits. The interference fringes are observed on a screen placed in front of the slits. Now, if a thin transparent glass plate is introduced normally in one of the beam, then

(a) fringe will disappear

(b) fringe width will increase

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17. If in Young's double slit interference experiment, the distance between the two slits is made three times, keeping all other conditions same, then the fringe width becomes

(a) one third (b) one ninth

(c) nine times (d) three times

Ans : **Main 2022 Sem-II**

As, fringe width in YDSE is given by,

$$\beta = \frac{D\lambda}{d}$$

Since, D and λ are constants, so $\beta \propto \frac{1}{d}$

Hence, if distance between two slits (d) is made three times, then fringe width will become one-third.

Thus (a) is correct option.

18. In Young's double slit experiment, what is the effect on fringe pattern, if the slits are brought closer to each other?

(a) Fringes disappear

(b) Fringe width increases

(c) Fringe width decreases

(d) Fringe width remains unaltered

Ans : **Main 2022 Sem-II**

Fringe width,

$$\beta = \frac{D\lambda}{d}$$

If two slits are brought closer to each other, d decreases, i.e. $\beta \propto 1/d$. So, fringe width β increases.

Thus (b) is correct option.

19. A diffraction pattern is obtained by using a beam of red light. What happens, if the red light is replaced by blue light?

(a) no change

(b) diffraction bands disappear

(c) diffraction bands become broader and farther apart

(d) diffraction bands become narrower and crowded together

Ans : **Main 2017**

Width of a diffraction pattern for central band,

$$\beta = \frac{\lambda D}{d} \propto \lambda$$

Since, wavelength of blue light is less than that of red light, therefore width of the bands is reduced or bands becomes narrower and crowded together.

Thus (d) is correct option.

20. The phenomenon of diffraction can be treated as the phenomenon of interference, if the number of coherent sources are

(a) one (b) two

(c) zero (d) infinite

Ans : **SQP 2007**

We know from the wave theory that diffraction at a single slit is equivalent to the interference of light from infinite number of coherent sources contained in the slit. Therefore the phenomenon of diffraction can be treated as interference phenomenon, if the number of coherent sources are infinite.

Thus (d) is correct option.

NODIA

21. The colour of a thin film is due to

(a) scattering (b) interference

(c) dispersion (d) diffraction

Ans : **SQP 2015**

The colours seen in a thin film, such as soap bubbles or oil films on water, are produced due to the interference of light waves reflected from the upper and lower surfaces of the thin film. Different colours are formed because different wavelengths undergo constructive and destructive interference at different points.

Thus (b) is correct option.

22. When exposed to sunlight, thin films of oil on water often exhibit brilliant colours due to the phenomenon of

(a) interference (b) diffraction

(c) dispersion (d) polarisation

Ans : **SQP 2005**

When a thin films of oil on water is exposed to sunlight, then light waves, reflected from the upper and lower surfaces of the thin film of oil interfere with each other.

And the brilliant colours due to the constructive and destructive interference, depends upon wavelength the light.

As a result of this, thin films of oil on water often exhibit brilliant colours due to the phenomenon of interference.

Thus (a) is correct option.

23. Laser light is considered to be coherent as it consists of

(a) divergent beam

(b) different wavelengths

(c) uncoordinated wavelength

(d) coordinated waves of same wavelength

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Main 2014**

In Young's experiment, fringe width of dark and white fringes are equal. If white light is used as source, coloured fringes are observed representing bright band of different colours.

Thus (d) is correct option.

34. **Assertion :** When tiny circular obstacle is placed in the path of light from some distance, a bright spot is seen at the centre of the shadow of the obstacle.

Reason : Destructive interference occurs at the centre of the shadow.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **SQP 2005**

A bright spot is found at the centre of circular fringe patterns formed due to diffraction of light at the edge of circular obstacles. This bright spot is due to constructive interference there by secondary wavelets.

Thus (c) is correct option.

35. **Assertion :** Goggles have zero power.

Reason : Radius of curvature of both sides of lens is same.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Main 2013**

Goggles protect from harmful UV light of sun rays and do not correct sight defects hence have zero power.

Both lens of goggles are identical hence have same curvature.

Thus (b) is correct option.

36. **Assertion :** No interference pattern is detected when two coherent sources are infinitely close to each other.

Reason : The fringe width is inversely proportional to the distance between the two slits.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **SQP 2024, 2009**

When d is negligibly small, fringe width β which is proportional to $1/d$ may become too large. Even a single fringe may occupy the whole screen. Hence the pattern cannot be detected.

Thus (a) is correct option.

37. **Assertion :** A white source of light during interference forms only white and black fringes.

Reason : Width of fringe is inversely proportional to the wavelength of the light used.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Comp 2005**

A white source of light during interference will form coloured fringes.

Fringe width is given by $\beta = \frac{\lambda D}{d}$ i.e., it is directly proportional to wavelength.

Thus (d) is correct option.

38. **Assertion :** Thin films such a soap bubble or a thin layer of oil on water show beautiful colours when illuminated by white light.

Reason : It happens due to the interference of light reflected from the upper surface of the thin film.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

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(c) fringe width will decrease

(d) fringe width remains the same

Ans : **Main 2016**

If a thin transparent sheet of some refractive index is introduced normally in the path of one of the interfering waves (or beam), then the entire interference fringe pattern is shifted through some distance without any change in the fringe width. Therefore if a thin glass plate which is transparent is introduced normally in one of the beam, then fringe width remains the same.

Thus (d) is correct option.

30. In Young's double slit experiment, if separation between the slits is halved and distance between the slits and screen is doubled, then fringe width will

(a) be halved (b) be two times

(c) be four times (d) remains constant

Ans : **Main 2002**

Final distance between the slits,

$$d_2 = \frac{d_1}{2}$$

Where, d_1 = initial distance between the slits and final distance between slit and screen

$$D_2 = 2D_1$$

Where, D_1 = initial distance between slit and screen fringe width,

$$\beta = \frac{\lambda D}{d} \propto \frac{D}{d}$$

Therefore $\frac{\beta_1}{\beta_2} = \frac{D_1}{D_2} \times \frac{d_2}{d_1} = \frac{D_1}{2D_1} \times \frac{\frac{d_1}{2}}{d_1} = \frac{1}{4}$

or $\beta_2 = 4\beta_1$

Thus the fringe width will be quadrupled.

Thus (b) is correct option.

31. A single slit of width 0.5 mm is illuminated by parallel light of wavelength 5000 Å and diffraction pattern is observed on a screen 1 m from the slit. The width of the central maxima is

(a) 500 mm (b) 600 mm

(c) 700 mm (d) 800 mm

Ans : **Main 2011**

Width of slit, $a = 0.5\,\text{mm} = 0.5 \times 10^{-3}\,\text{m}$

Wavelength of light, $\lambda = 5000\,\text{Å} = 5000 \times 10^{-10}\,\text{m}$

and distance between slit and screen,

$$D = 1\,\text{m}$$

width of central maxima,

$$\beta = \frac{2\lambda D}{a}$$

$$= \frac{2 \times (5000 \times 10^{-10}) \times 1}{0.5 \times 10^{-3}}$$

$$= 500 \times 10^{-3}\,\text{m} = 500\,\text{mm}$$

Thus (d) is correct option.

ASSERTION AND REASON

DIRECTION : These questions consist of two statements, each printed as Assertion and Reason. While answering these questions, you are required to choose any one of the following five responses.

32. **Assertion (A) :** In Young's double slit experiment all fringes are of equal width.

Reason (R) : The fringe width depends upon wavelength of light (λ) used distance of screen from plane of slits (D) and slits separation (d).

(a) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).

(b) Both Assertion (A) and Reason (R) are true and Reason (R) is NOT the correct explanation of Assertion (A).

(c) Assertion (A) is true and Reason (R) is false.

(d) Assertion (A) is false and Reason (R) is also false.

Ans : **SQP 2023**

The fringe width is given as :

$$\beta = \frac{\lambda_0}{d}$$

So, if λ, D and d remains constant, then fringe width remains constant.

Thus (a) is correct option.

33. **Assertion :** In Young's experiment, the fringe width for dark fringes is different from that for white fringes.

Reason : In Young's double slit experiment the fringes are performed with a source of white light, then only black and bright fringes are observed.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

NODIA

9. Huygen's wave theory of light can not explain
(a) diffraction
(b) interference
(c) polarisation
(d) photoelectric effect

Ans : Main 2014, 2003

The Huygen's wave theory of light can explain reflection, refraction, interference, polarisation and diffraction, while quantum theory can explain the photoelectric effect.

Thus (d) is correct option.

10. In Young's double slit experiment, if one slit is covered with red filter and the other slit is covered by green filter, then their interference pattern will be
(a) red (b) green
(c) yellow (d) invisible

Ans : Main 2015

Red and green colours are complementary to each other. Therefore if one slit is covered with red filter and another slit is covered by green filter, then their interference pattern will be invisible.

Thus (d) is correct option.

11. If light waves emitted by two coherent sources have wavelengths λ_1 and λ_2, then
(a) $\lambda_1 = \lambda_2$ (b) $\lambda_1 > \lambda_2$
(c) $\lambda_1 < \lambda_2$ (d) $\lambda_1\lambda_2 = 1$

Ans : Main 2002

The light waves emitted from two coherent sources have same wavelength, same frequency and are in same phase or have a constant phase difference

Therefore, $\lambda_1 = \lambda_2$

Thus (a) is correct option.

12. The bending of beam of light around the corners of an obstacle is called
(a) reflection (b) refraction
(c) diffraction (d) interference

Ans : SQP 2007

The phenomenon of bending of light around the corners of an obstacle or aperture in the path of light is called diffraction.

Thus (c) is correct option.

13. When light is incident on a diffraction grating, then zero order principal maxima will be
(a) white
(b) absent
(c) spectrum of the colours
(d) one of the component colours

Ans : SQP 2003

When light is incident on a diffraction grating, then diffraction bands obtained are coloured. But the zero order principal maxima will be white.

Thus (a) is correct option.

14. Which of the following can not be polarised?
(a) radio waves
(b) ultrasonic waves
(c) ultra-violet-rays
(d) X-rays and infra-red rays

Ans : SQP 2013

Ultrasonic waves can not be polarised, because these waves are longitudinal in nature.

Since radio-waves ultra-violet rays X-rays, infra-red rays are transverse in nature, therefore they can be polarised.

Thus (b) is correct option.

15. The diffraction of sound waves is easier than light waves, because the sound waves are
(a) longitudinal
(b) mechanical waves
(c) of shorter wavelength
(d) of longer wavelength

Ans : Comp 2024

A wave is diffracted only when size of the obstacle is comparable with the wavelength of the wave.

Since wavelength of sound waves is longer than light waves, therefore their diffraction is easier than light waves around big obstacles.

Thus (d) is correct option.

16. When a compact disc is illuminated by a source of white light, coloured lanes are observed. This is due to
(a) dispersion (b) diffraction
(c) interference (d) refraction

Ans : Main 2014, 2009

when a compact disc is illuminated by a source of white light, then the small ripples on the surface of disc, break up white light into different colours due to diffraction. As a result of this, coloured lanes are observed.

Thus (b) is correct option.

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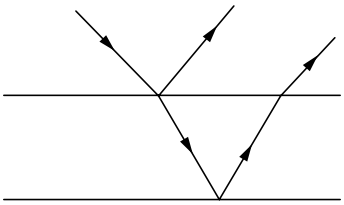
(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : SQP 2012

Interference in between two rays, one is reflected from the upper surface and second from the lower surface.



Thus (c) is correct option.

39. **Assertion :** A famous painting was painted by not using brush strokes in the usual manner, but rather a myriad of small colour dots. In this painting the colour you see at any given place on the painting changes as you move away.

Reason : The angular separation of adjacent dots changes with the distance from the painting.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : Main 2017

We see two closely situated very small dots separate when their angular separation for the viewer is more than that required by Rayleigh's criterion.

$$\theta_R = 1.22\frac{\lambda}{d}$$

Here, d is diameter of eye and λ is wavelength of light seen.

If distance between spot is D and L be the distance of observer from the painting then,

$$\theta = \frac{D}{L}$$

So, $$1.22\frac{\lambda}{d} = \frac{D}{L}$$

$$L = \frac{Dd}{1.22\lambda}$$

In for red light having greater λ, the value of L will be smaller and for violet colour, this distance is large. If we move away from the painting, adjacent red dots become indistinguishable before adjacent blue dots do. So, to make two dots distinguishable we shall have to give distance of the observer (L) a minimum value. At a greater distance colours of adjacent dots blend together. In this way we can have different view of dots by looking at it from different distance (or changing L). So, both assertion and reason are correct.

Thus (a) is correct option.

ONE MARK QUESTIONS

40. What type of wave front is generated from a line source of light?

Ans : Main 2017, 2008, 2004

A line source of light produces cylindrical wavelength.

41. State one condition for obtaining sustained interference of light.

Ans : Main 2014, 2011

The sources must be coherent for obtaining sustained interference of light.

42. What is the phase difference between any two points lying on the same wave front?

Ans : Main 2020

The phase difference between any two points lying on the same wave front is zero.

43. Define the term 'wavefront'.

Ans : SQP 2025

It is defined as the locus of all points in a medium vibrating in the same phase.

44. Define coherent sources of light.

Ans : Main 2022 Sem-II, 2018, 2014

Coherent sources of light are the sources which emit light waves of same frequency and have zero phase difference.

45. Can two independent monochromatic sources of light be coherent? Explain very briefly.

Ans : Main 2000

As phase difference between two independent monochromatic sources of light keeps on changing with time, hence the sources cannot be coherent.

NODIA

46. What is meant by coherent sources of light?

Ans : **Main 2014**

Two sources of light having same frequency and constant phase difference with time are known as coherent sources of light.

47. Define the term 'coherent sources' which are required to produce interference pattern in Young's double slit experiment.

Ans : **Main 2018**

Two monochromatic sources, which produce light waves, having a constant phase difference are known as coherent sources.

48. Can two sodium vapour lamps act as coherent sources? Explain in brief

Ans : **Main 2009**

The light waves emitted by two sodium vapour lamps cannot be coherent. The conditions of maxima and minima will change rapidly on the screen producing a uniform illumination.

49. What will be the effect of interference fringes if red light is replaced by blue light ?

Ans : **Main 2019**

$\beta = \frac{D\lambda}{d}$, i.e., $\beta \propto \lambda$; the wavelength of blue light is less than that of red light is less than that of red light, hence if red light is replaced by blue light, the fringe width decrease, i.e., fringes come closer.

50. How does the angular separation between fringes in single-slit diffraction experiment change when the distance of separation between the slit and screen is doubled ?

Ans : **Comp 2020**

Angular separation is, $\theta = \frac{\beta}{D} = \frac{\frac{D\lambda}{d}}{D} = \frac{\lambda}{d}$

Since θ is independent of D, angular separation would remain same.

51. Can white light produce interference? What is its nature?

Ans : **Comp 2016**

Yes, white light can produce interference. In this case, the central fringe will be white and first few colored fringes will be formed and then the fringes of different colors overlap to produce general illumination, white in color.

52. In Young's double slit experiment, if white light is used in place of monochromatic light, what changes are observed in the interference pattern?

Ans : **Main 2004**

The interference pattern due to different component colours of white light overlap (incoherently). The central bright fringes for different colours are at the same position and therefore the central bright fringe is white. And offer few fringe no clear fringe pattern is seen.

53. In Young's double slit experiment, what is the path difference between the two light waves forming 5^{th} bright fringe on the screen?

Ans : **SQP 2023**

Path difference for the nth bright band,

$$\delta = 2n \cdot \lambda/2 = n\lambda$$

$$n = 5$$

So, $$\delta = 5\lambda$$

54. State any one difference between interference of light and diffraction of light.

Ans : **Main 2015**

The interference pattern has a number of equally spaced bright and dark bands. The diffraction pattern has a central bright maxima, which is twice as wide as the other maxima. The intensity falls, as we go to successive maxima away from the centre on either side.

55. State Huygen's principle of diffraction of light ?

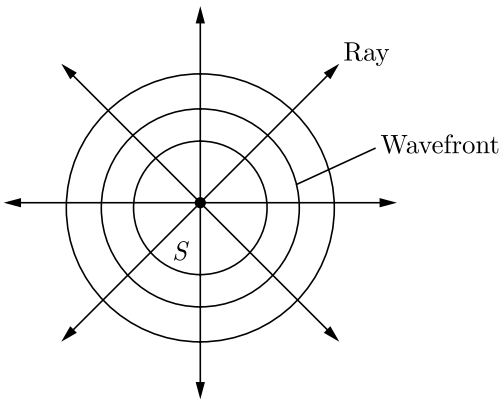
Ans : **Comp 2021**

When a wavefront strikes to the corner of an obstacle, light wave bends around the corner because every point on wavefront again behaves like a light source and emit secondary wavelets in all directions (Huygen's wave theory) including the region of geometrical shadow. This explains diffraction.

56. What is the shape of the wave front diverging from a point source of light?

Ans : **Main 2024**

The shape of the wave front diverging from a point source is spherical as shown in the figure.



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57. In what way is the diffraction from each slit related to interference pattern in double slit experiment ?

Ans : **SQP 2020**

The intensity of interference fringes in a double slit arrangement is modulated by the diffraction pattern of each slit. Alternatively, in double slit experiment the interference pattern on the screen is actually superposition of single slit diffraction for each slit.

58. State anyone postulate of Huygens' wave theory.

Ans : **Main 2011, 2003, 2001**

According to Huygens' principle, each point on the given wave front (called primary wave front) is the source of a secondary disturbance (called secondary wavelets) and the wavelets emanating from these points spread out in all directions with the speed of the wave.

59. Write down the expression of fringe width in interference.

Ans : **SQP 2014**

Fringe width, $\beta = \frac{\lambda D}{d}$

where, $\lambda =$ wavelength of light

$D =$ Distance of screen from slit

$d =$ Distance between slit

60. What should be the path difference between two waves reaching a point for obtaining constructive interference in Young's double slit experiment?

Ans : **Main 2019**

Path difference x between the interfering waves,

$$x = \frac{\lambda}{2\pi}\phi$$

For maximum intensity, $\phi = 2m\pi$

$$x = \frac{\lambda}{2\pi}(2m\pi)$$

$$x = m\lambda$$

61. How is fringe width of an interference pattern in Young's double slit experiment affected if the two slits are brought closer to each other?

Ans : **Main 2017**

According to Young's double slit experiment, fringe width $\beta = \frac{D\lambda}{d}$

where, $D =$ distance between slit and screen

$d =$ distance between two slits

If d decreases, i.e. distance between two slits decrease, β will increases.

62. In a single-slit diffraction experiment, the width of the slit is made double the original width. How does this affect the size and intensity of the central diffraction band ?

Ans : **Main 2012**

In single slit diffraction experiment fringe width is

$$\beta = \frac{2\lambda D}{d}$$

If d is doubled, the width of central maxima is halved. Thus, size of central maxima is reduced to half. Intensity of diffraction pattern varies square of slit width. So, when the slit gets double, it makes the intensity four times.

63. Young's double slit experiment was performed with monochromatic light of blue colour. The experiment was then repeated, first with light of red colour and then with light of yellow colour. Which colour pattern will have maximum separation (i.e, fringe width)?

Ans : **Main 2010, 2008, 2006**

In YDSE, we know the fringe width,

$$\beta = \frac{D\lambda}{d}$$

where, D distance between source and screen and d is distance between sources (i.e. slits). As D and d are fixed,

i.e. $\beta \propto \lambda$

And λ for red is more than λ for blue. So, β is more for red colour.

64. In a single slit Fraunhofer diffraction experiment, how does the angular width of central maximum change when the slit width is increased?

Ans : **Main 2023**

In Fraunhofer diffraction, $b\sin\theta = n\lambda$

Where, b in the width of slit, λ is the wavelength of light used.

For central bright fringe,

$$n = 1$$

$$b\sin\theta = \lambda$$

Thus, angular width of central bright

$$\text{angular width} = 2\sin\theta = \frac{2\lambda}{b}$$

So, angular width of central bright fringe will decrease when the width of slit is increased.

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TWO MARKS QUESTIONS

65. If the width of the slit is made double the original width, how does it affect the size and intensity of the central band?

Ans : **Main 2013**

If a is doubled, β becomes half and intensity becomes 4 times.

66. What is meant by constructive interference?

Ans : **Main 2022 Sem-II**

At the point, where the resultant intensity of light is maximum, the interference is said to be constructive.

67. Explain why the maxima at $\theta = \left(n+\frac{1}{2}\right)\frac{\lambda}{d}$ become weaker and weaker with increasing n.

Ans : **Comp 2017**

On increasing the value of n, the part of slit contributing to the maximum decrease. Hence, the maximum becomes weaker.

68. State the essential conditions for diffraction of light.

Ans : **Main 2025**

Essential conditions for diffraction of light

(a) Sources of light should be monochromatic.

(b) Wavelength of the light used should be comparable to the size of the obstacle.

69. When a tiny circular obstacle is placed in the path of light from a distant source, a bright spot is seen at the centre of shadow of the obstacle. Explain.

Ans : **Main 2008**

The light waves diffracted from the edges of the circular obstacle interfere destructively at the center of the shadow producing bright spot at the center of the shadow.

70. What is meant by diffraction of light?

Ans : **Main 2022 Sem-II**

The phenomenon of bending of light around the edges or the sharp corners and then spreading of light within the geometrical shadow of opaque obstacles is called diffraction of light.

71. What is meant by diffraction of light?

Ans : **Main 2017**

The phenomenon of bending of light around the edges or the sharp corners and then spreading of light within the geometrical shadow of opaque obstacles is called diffraction of light.

72. What is the essential condition for obtaining a sustained interference?

Ans : **Main 2023**

The conditions for sustained interference for are as follows:

1. The two sources of light must be coherent.
2. The amplitude of electric field vector of interfering wave should be equal to have greater contrast.

73. In Young's double slit experiment, plot a graph showing the variation of fringe width versus the distance of the screen from the plane of the slits keeping other parameters same. What information can one obtain from the slop of the curve?

Ans : **Main 2012**

Information from the slope :

Wavelength, $\lambda = \text{slope} \times d = d \cdot \tan\theta$

74. 'Two independent monochromatic sources of light cannot produce a sustained interference pattern'. Give reason.

Ans : **Main 2014**

The light waves, originating from two independent monochromatic sources, will not have a constant phase difference for wave reaching at a point. Therefore, these sources will not be coherent and therefore would not produce a sustained interference pattern.

75. State any one difference between diffraction of light and interference of light.

Ans : **Comp 2006**

The interference pattern has a number of equally spaced bright and dark bands. The diffraction pattern has a central bright maxima, which is twice as wide as the other maxima. The intensity falls, as we go to successive maxima away from the centre on either side.

76. Light from two coherent sources is reaching the screen. If the path difference at a point on the screen for the yellow light be $\frac{3\lambda}{2}$, then what will be the colour of the fringe at that point?

Ans : **SQP 2019**

If the light is white, the fringes will be colored, however, the yellow and neighbouring colors shall be absent. If the source is emitting yellow light (i.e. monochromatic) there will be dark fringe at that point.

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77. Why light can travel in vacuum whereas sound cannot do so?

Ans : **Main 2009, 2005**

Light wave are electromagnetic waves and hence do not require any material medium for propagation hence light can travel in vacuum. The sound waves are mechanical waves and a material medium is must for them to travel, hence they cannot travel in vacuum.

78. Why are coherent sources necessary to produce a sustained interference pattern ?

Ans : **SQP 2014**

This is because coherent sources are needed to ensure that the positions of maxima and minima do not change with time.

If the phase difference between wave, reaching at a point change with time, intensity will change and sustained interference will not be obtained.

79. In Fraunhofer diffraction, what kind of source of light is used and where is it situated?

Ans : **Main 2024**

In this type of diffraction, the source of light is not necessary to be monochromatic or white light but the expression calculated for the central maxima and minima, we considered it to be monochromatic. And the source of light is being placed at large distance from the screen i.e. effectively at infinity.

80. Why two independent sources cannot produce sustained interference?

Ans : **Comp 2017**

The two independent sources cannot act as coherent sources because the phase difference changes 10^8 times in one second and due to this fast variation of phase, the position of maxima and minima also varies, so the interference pattern but undetected i.e. the two independent sources can not produce sustained interference.

81. Radio-waves diffract pronouncedly around buildings, while light waves, which are electromagnetic waves, do not. Why?

Ans : **Main 2010**

Since phenomenon of diffraction is observed only when size of the obstacle is comparable to the wavelength of the wave. The wavelength of radio waves (particularly short waves) have wavelength comparable to general objects like buildings and hence easily get diffracted. But wavelength of light is very small (3900Å to 7800Å). So they are not diffracted.

82. Can two electric bulbs of same power and having filaments of the same material placed close to each other produce interference on the screen?

Ans : **Comp 2018**

No, the interference pattern will not be obtained on the screen because the two electric bulbs are not coherent sources and the path difference from two incoherent sources will change randomly. Thus sustained interference pattern will not be observed but there will be general illumination on the screen.

83. What happens to the interference pattern when two coherent sources are

(a) infinitely dose, and

(b) far apart from each other.

Ans : **SQP 2023**

(a) No interference pattern is detected when two coherent sources are infinitely close to each other.

(b) If the sources are far apart, d is large, so 'fringe width 0) will be so small that the fringes are not resolved and they do not appear separate. That is why the interference pattern is not detected for large separation of coherent sources.

84. Why are two bulbs lighting the same walls considered as incoherent sources? How do their intensities add up?

Ans : **Main 2015**

The bulbs are incoherent source at any frequency, the radiation from one has no stable phase relation with the other. This is because independent atoms and electrons are responsible for the radiation for each source.

For two different frequencies, the interference term becomes zero.

Hence, the intensities of two bulbs get up.

i.e., $I = I_1 + I_2.$

85. Find the relation for width of central maximum in terms of wavelength λ, width of slit a, and separation between slit and screen D.

Ans : **SQP 2001**

If θ is the direction of first minima, then $a\theta = \lambda$

$$\theta = \frac{\lambda}{a}$$

Angular width of central maxima $= 2\theta = \frac{2\lambda}{a}$

Linear width of central maxima,

$$\beta = 2\theta \cdot D = \frac{2\lambda D}{a}$$

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or $$t = \frac{AF\sin i}{c} + \frac{FC\sin r}{c}$$

$$t = \frac{AC\sin r + AF(\sin i - \sin r)}{c}$$

$$[FC = AC - AF]$$

For rays of light from different parts on the incident wave front, the values of AF are different. But light from different points of the incident wave front should take the same time to reach the corresponding points on the reflected wave front.

So, t should not depend upon AF. This is possible only, if

$$\sin i - \sin r = 0$$

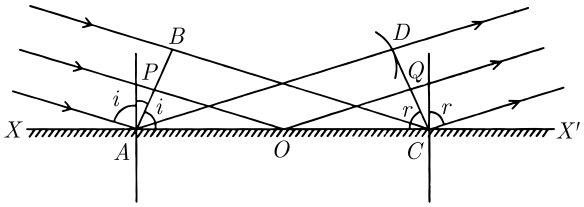
i.e. $$\sin i = \sin r \text{ or } \angle i = \angle r$$

which is the first law of reflection.

Further, the incident wave front AB, the reflecting surface XY and the reflected wave front CD are all perpendicular to the plane of the paper. Therefore, incident ray, normal to the mirror XY and reflected ray all lie in the plane of the paper. This proves the second law of reflection.

120. On the basis of Huygens' wave theory, show that when light is incident on a plane mirror obliquely, angle of reflection is equal to the angle of incidence.

Ans : **Main 2010, 2006**



where, XX' = reflecting surface

AB = incident wavefront

$\angle i$ = incident angle

CD = reflected wavefront

$\angle r$ = reflected angle

c = speed of light

The point P on incident wavefront is reached at Q on reflected wavefront in time t, as taken by point A to reach at D and point B to reach at C.

i.e., $$t = \frac{PO}{c} + \frac{OQ}{c}$$

In ΔAPO, $$\sin i = \frac{PO}{AO}$$

$$PO = AO\sin i$$

In ΔCQO, $$\sin r = \frac{OQ}{OC}$$

$$OQ = OC\sin r$$

Hence, $$t = \frac{AO\sin i + OC\sin r}{c}$$

$$= \frac{AO\sin i + AC\sin r - AO\sin r}{c}$$

$$= \frac{AO(\sin i - \sin r) + AC\sin r}{c}$$

AO and AC independent on time, hence we get

$$\sin i - \sin r = 0$$

$$\sin i = \sin r$$

$$\angle i = \angle r$$

121. In the experiment of diffraction due to a single slit, show that

(i) the intensity of diffraction fringes decreases as the order (n) increases.

(ii) angular width of the central maximum is twice that of the first order secondary maximum.

Ans : **SQP 2011**

(i) In diffraction due to a single slit the path difference is given by :

$$\Delta x = a\sin\theta$$

where, a is the width of the slit

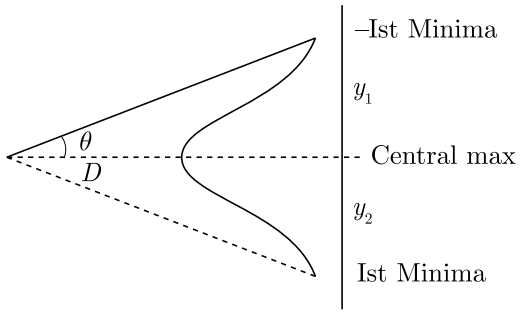
For maxima, $\Delta x = (2x+1)\frac{\lambda}{2}$

$$\Delta x = a\sin\theta = (2x+1)\frac{\lambda}{2}$$

For $$x = 1,\ \sin\theta = \frac{3\cdot\lambda}{2a}$$

Let us divide the slit into three equal parts. If we take first two parts of slit, the path difference between rays diffracted from the extreme ends of first two parts.

$$\frac{2}{3}a\sin\theta = \frac{2}{3}a \times \frac{3\lambda}{2a} = \lambda$$



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and $D' = \frac{D}{2}$

Hence, $\beta' = \frac{\lambda D'}{d'} = \frac{\lambda D}{2.2d} = \frac{\lambda D}{4d}$

Using Eq. (1), we get

$$\beta' = \frac{\beta}{4}$$

So the fringe width is reduced to one-fourth of its previous value.

93. What will be the effect on the width of the central bright fringe in the diffraction pattern of a single slit, if

(i) the monochromatic light of smaller wavelength is used.

(ii) slit is made narrower.

Ans : **Main 2013**

Width of the central bright fringe in the diffraction pattern of a single slit is

$$\beta = \frac{2D\lambda}{d}$$

where, D = distance of the screen

d = width of the slit

λ = wavelength of light

(i) As $\beta \propto \lambda$, when λ is smaller, then β decreases.

(ii) As $\beta \propto \frac{1}{d}$, when slit is made narrower, β increases.

94. Light waves each of amplitude a and angular frequency ω, emanating from two coherent light sources superpose at a point. If the displacements due to these waves is given by $y_1 = a\cos\omega t$ and $y_2 = a\cos(\omega t + \phi)$ where ϕ is the phase difference between the two. Obtain the expression for the resultant intensity at the point.

Ans : **SQP 2009**

The resultant displacement will be given by

$$\begin{aligned} y &= y_1 + y_2 \\ &= a\cos\omega t + a\cos(\omega t + \phi) \\ &= a[\cos\omega t + \cos(\omega t + \phi)] \\ &= 2a\cos\frac{\phi}{2}\cos\left(\omega t + \frac{\phi}{2}\right) \end{aligned}$$

The amplitude of the resultant displacement is $2a\cos\left(\frac{\phi}{2}\right)$. The intensity of light is directly proportional to the square of amplitude of the wave. The resultant intensity will be given by

$$I = 4a^2\cos^2\frac{\phi}{2}$$

95. If d is the distance covered by a light wave in the air in t seconds and D is the distance covered in a medium of refractive index μ in the same time, then prove that $d = \mu D$.

Ans : **Main 2006**

Refractive index of medium (μ)

$$= \frac{\text{Speed of light in air } (c)}{\text{Speed of light in medium } (v)}$$

Let c_1 be the velocity of light in the air, then time t taken by it to cover a distance d is

$$t = \frac{d}{c_1}$$

or $$c_1 = \frac{d}{t}$$

If c_2 is the velocity of light in the medium and during the same time t, a light cover a distance D is

$$\frac{c_1}{c_2} = \frac{d/t}{D/t}$$

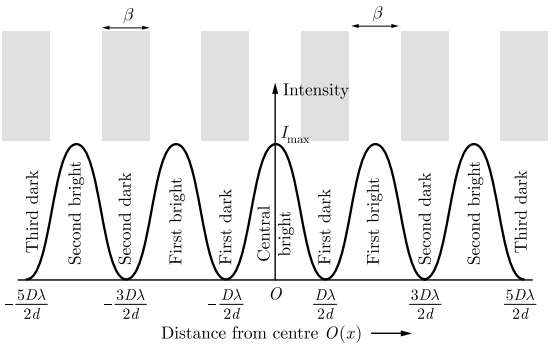
$$\mu = \frac{d}{t} \times \frac{t}{D} = \frac{d}{D}$$

$$d = \mu D \qquad \left[\frac{c_1}{c_2} = \mu\right]$$

96. Draw a graph showing the variation of intensity against the position x on the screen in Young double slit experiment.

Ans : **Main 2020**

On plotting the intensities of bright and dark fringes against distance x from O, we get a curve as shown in figure. The intensity is maximum at the central point O. Then it becomes zero and maximum alternately on either side of O, depending on x is odd multiple of $\frac{D\lambda}{2d}$ and integral multiple of $\frac{D\lambda}{d}$, respectively.



Intensity Distribution Curve for an Interference Pattern

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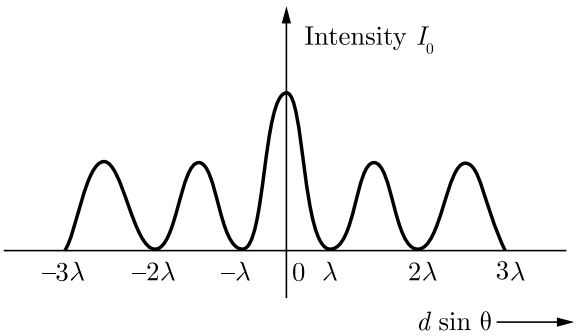
97. Show graphically, the intensity distribution in Fraunhofer's single slit diffraction experiment. Label the axes.

Ans : **Main 2015**

The graph of variation in the intensity of diffracted light in a single slit experiment is shown in the figure. Here, intensity of the central maxima will be maximum and that of other will gradually decrease.



For central bright fringe, $\theta = 0^\circ$

For first dark fringe,

$$d\sin\theta = \pm\lambda \Rightarrow \sin\theta = \pm\frac{\lambda}{d}$$

98. Two sources of intensity I_1 and I_2 undergo interference in Young's double slit experiment. Show that $\frac{I_{max}}{I_{min}} = \left(\frac{a_1+a_2}{a_1-a_2}\right)^2$, where a_1 and a_2 are the amplitudes of disturbance of two sources S_1 and S_2.

Ans : **Comp 2020**

Let, a_1 and a_2 be the amplitudes and I_1 and I_2 be the intensities of light waves from two different sources.

As, Intensity $\propto$ Amplitude^2

Hence, $\frac{I_1}{I_2} = \frac{a_1^2}{a_2^2}$

Amplitude at a maximum in interference patten

$$= a_1 + a_2.$$

Amplitude at a minimum in interference patten

$$= a_1 - a_2.$$

Therefore, the ratio of intensities at maxima and minima is,

$$\frac{I_{max}}{I_{min}} = \frac{(a_1+a_2)^2}{(a_1-a_2)^2} = \frac{\left(\frac{a_1}{a_2}+1\right)^2}{\left(\frac{a_1}{a_2}-1\right)^2}$$

or $$\frac{I_{max}}{I_{min}} = \left[\frac{r+1}{r-1}\right]^2$$

Where, $r = \frac{a_1}{a_2}\sqrt{\frac{I_1}{I_2}}$

= amplitude ratio of the two waves

99. Two independent sources of light cannot be coherent. Explain why.

Ans : **SQP 2020, 2016**

This is because of the following reasons:

1. Light is emitted by individual atoms and not by the bulk of matter acting as a whole.
2. Even a tiniest source consists of millions of atoms and emission of light by them takes place independently.
3. Even an atom emits an unbroken wave of about 10^{-8} second due to its transition from a higher energy state to a lower energy state.

The millions of atoms of a source cannot emit waves in the same phase. The light emitted by the commonly used monochromatic source (a sodium lamp) remains coherent for about 10^{-8} s. After this time, the atoms responsible for emission of light get changed. The phase difference and hence the interference pattern changes 10^8 times in one second. Our eyes cannot see such rapid changes and a uniform illumination is seen on the screen. So two independent light sources cannot produce a sustained interference.

THREE MARKS QUESTIONS

100. In Young's double slit experiment, what is meant by 'fringe width' or 'fringe separation'? State two ways of increasing the fringe width without changing the source of light.

Ans : **Main 2009, 2001**

Fringe width is the separation between two consecutive bright or dark fringes.

The fringe width, $\beta = \frac{\lambda D}{d}$

To increase fringe width (β) without changing source of light, we should

(i) increase D (distance between slit and screen)

(ii) decrease d (distance between two slits)

101. State briefly two features which can distinguish the characteristic features of an interference pattern from those observed in the diffraction pattern due to a single slit.

Ans : **SQP 2018**

Features of interference pattern are given below.

(i) The interference pattern has a number of equally a central bright maximum which is twice as wide as the other maxima. The intensity in diffraction pattern falls as we go to successive maxima away from the centre on either side.

(ii) We calculate the interference patten by superposing two waves originating from the two narrow slits. The diffraction pattern is a superposition of a continuous family of waves originating from each point on a single slit.

102. Compare single slit diffraction pattern due to monochromatic light and whit light.

Ans : **Main 2016**

When source of light is monochromatic, the diffraction pattern consists of alternate bright and dark bands of unequal width. The central bright fringe has maximum intensity. The intensity of secondary maxima falls off rapidly.

When source is emitting white light, the diffraction pattern is colored. The central maxima is white, but other bands are colored. As band width is directly proportional to the $\propto \lambda$, therefore, red band with higher wavelength is wider than violet with smaller wavelength.

103. Write the necessary conditions to obtain sustained interference fringes. Also write the expression for the fringe width.

Ans : **Comp 2025**

Conditions for sustained interference

(i) The interfering sources must be coherent i.e., source must have same frequency and constant initial phase.

(ii) Interfering waves must have same or nearly same amplitude, so that there may be contrast between maxima and minima.

$$\text{Fringe width } \beta = \frac{D\lambda}{d}$$

where D = distance between slits and screen

d = separation between slits

λ = wavelength of light

104. In a single slit diffraction experiment, how does the angular width of the central maxima change when

(a) screen is moved away from the plane of the slit?

(b) width of the slit is increased?

(c) light of larger wavelength is used?

Ans : **Main 2022 Sem-II**

(a) Angular width remains unchanged when the screen is moved away from the plane of the slit.

(b) As, angular width $= \frac{2\lambda}{d}$

where, d is the slit width.

If slit width increases, angular width decreases.

(c) If the light of larger wavelength is used than the as per increase in wavelength, the angular width also increases because angular width is directly proportional to the wavelength.

105. Show that maximum intensity in interference pattern is four times the intensity due to each slit. Hence show that interference involves only redistribution of energy.

Ans : **SQP 2019, 2017**

Let, a be amplitude of waves from each slit, hence, a^2 is the intensity due to each slit.

Hence, Before interference,

$$\text{Average intensity} = a^2 + a^2 = 2a^2$$

So, $$\text{Maximum intensity} = (a+a)^2$$
$$= (2a)^2 = 4a^2$$

i.e. maximum intensity is four times the intensity due to each slit.

and $$\text{Minimum intensity} = (a-a)^2 = 0$$

Also average intensity in interference pattern

$$= \frac{0+4a^2}{2} = 2a^2$$

= Average intensity before interference

Hence the interference involves only redistribution of energy keeping the total energy constant.

106. What is difference between diffraction and interference?

Ans : **Main 2013**

Differences between interference and diffraction are as follows.

	Interference	**Diffraction**
1.	Interference is the result of superposition of light from two different wave fronts produced by two coherent sources.	Diffraction is the superposition of secondary waves emitted from various points of the same wave front.
2.	Interference fringes are of the same intensity.	Intensity of diffraction fringes fall rapidly.
3.	Interference fringes are equally spaced.	Diffraction fringes are unequally spaced.
4.	Minimas of interference fringes are of zero intensity.	In case of diffraction fringes, minimas are never perfectly dark.

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For the first minimum, take $m = 1$

$$A\theta_1 = \lambda$$

$$\theta_1 = \frac{\lambda}{A}$$

Now, angular width, $AB = \theta_1$

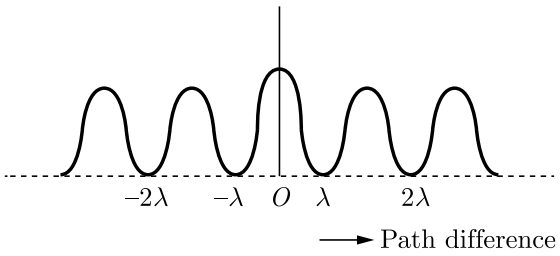
Angular width, $BC = \theta_1$

Angular width,s $AC = 2\theta_1$

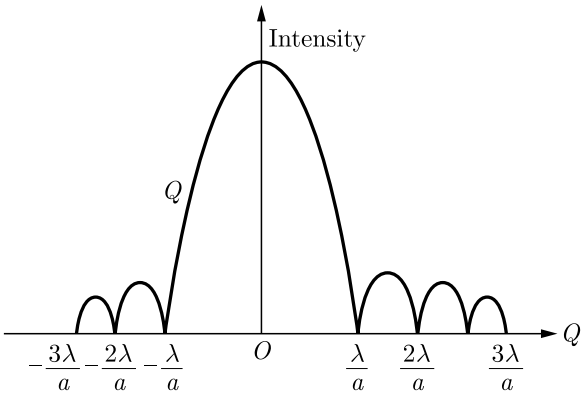
115. Draw the intensity pattern for single slit diffraction and double slit interference. Hence, state two difference between interference and diffraction patterns.

Ans : **Main 2013**

Intensity pattern for single slit diffraction



Intensity pattern for double slit interference



Difference between interference and diffraction

	Interference	**Diffraction**
1.	Fringe widths are same.	Fringe widths are different.
2.	Generally fringe pattern is hyperbolic.	Generally fringe pattern is circular.

116. A parallel beam of monochromatic light falls normally on a narrow slit of width d to produce a diffraction pattern on the screen placed parallel to the plane of the slit. Use Huygen's principle to explain that

(i) the central bright maxima is twice as wide as the other maxima.

(ii) the intensity falls as we move to successive maxima away from the centre on either side.

Ans : **SQP 2012**

(i) In diffraction pattern, intensity will be minimum at an angle $\theta = \frac{n\lambda}{d}$

Where, $d =$ width of slit and $n = 1, 2, 3, ...$

There will be a first minimum at an angle

$$\theta = \frac{\lambda}{d}$$

On either side of central maximum.

Since, Width of central maxima $= \frac{2\lambda}{d}$

Whereas the width of other minimum/ maximum $= \frac{\lambda}{d}$

(ii) The intensity of maxima decreases as the order (n) or diffraction maxima increases. This is because, on dividing the slit into odd number of parts, the contributions of the corresponding (outermost) pairs cancel each other, the contributions of the corresponding pair cancel each other, leaving behind the contribution of only the innermost segment e.g., for maxima, slit is dividing into three parts, out of these three parts of the slit, the contribution from first two parts cancel each other, only $\frac{1}{3}^{\text{rd}}$ position of slit contributes of the maxima of intensity. Similarly, for second maxima, slit is dividing into five parts, contribution of first four parts will be zero. The remaining $\frac{1}{5}^{\text{th}}$ portion will only contribute for maxima and so on.

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117. Two harmonic waves of monochromatic light $y_1 = a\cos\omega t$ and $y_2 = a\cos(\omega t + \phi)$ are superimposed on each other. Show that maximum intensity in interference pattern is four times the intensity due to each slit. Hence write the conditions for constructive and destructive interference in terms of the phase angle ϕ.

Ans : **SQP 2016**

The resultant displacement will be given by

$$y = y_1 + y_2$$

$$= a\cos\omega t + a\cos(\omega t + \phi)$$

$$= a[\cos\omega t + \cos(\omega t + \phi)]$$

$$= 2a\cos\left(\frac{\phi}{2}\right)\cos\left(\omega t + \frac{\phi}{2}\right)$$

The amplitude of the resultant displacement is $2a\cos\left(\frac{\phi}{2}\right)$.

The intensity of light is directly proportional to the square of amplitude of the wave. The resultant intensity will be given by

111. Give two differences between interference and diffraction of light.

Ans : **Main 2014, 2017**

Difference between interference and diffraction are as follows :

	Interference	Diffraction
(i)	It is due to the superposition of two waves coming from two coherent sources.	It is due to the superposition of secondary wavelets originating from different parts of the same wave-front.
(ii)	The width of the interference bands is equal.	The width of the diffraction bands is not the same.
(iii)	The intensity of all maxima (fringes) is same.	The intensity of central maximum is maximum and goes on decreasing rapidly with increase in order of maxima.

112. State two conditions required for obtaining coherent sources.

In Young' arrangement to produce interference pattern, show that dark and bright fringes appearing on the screen are equally spaced.

Ans : **SQP 2009**

Conditions for obtaining coherent sources :

(i) Coherent sources of light should be obtained from a single source by same device.

(ii) The two sources should give monochromatic light.

The separation between the centres or two consecutive bright fringes is the width of a dark fringe.

$$\beta = x_n - x_{n-1}$$

$$= n\frac{\lambda D}{2d} - (n-1)\frac{\lambda D}{2d} = \frac{\lambda D}{2d}$$

Similarly for dark fringe,

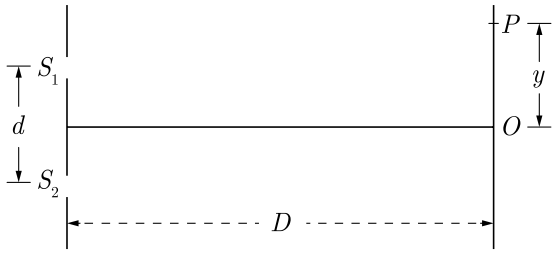
$$\text{fringe width}\,\beta' = x_n' - x'_{n-1}$$

$$= (2n-1)\frac{\lambda D}{2d} - [2(n-1)-1]\frac{\lambda D}{2d}$$

$$= \frac{\lambda D}{2d}$$

Hence, all bright and dark fringes are equally spaced on screen.

113. The intensity at the central maxima (O) in a Young's double slit experiment is I_0. If the distance OP equals one-third of the fringe width of the pattern, show that the intensity at point P would be $\frac{I_0}{4}$.



Ans : **Main 2011, 2012**

Fringe width, $\beta = \frac{\lambda D}{d}$ ...(1)

(From eq 1)

$$y = \frac{\beta}{3} = \frac{\lambda D}{3d}$$

Path difference, $\Delta p = \frac{yd}{D}$

$$\Delta p = \frac{\lambda D}{3d} \cdot \frac{d}{D} = \frac{\lambda}{3}$$

$$\Delta\phi = \frac{2\pi}{\lambda} \cdot \Delta p = \frac{2\pi}{\lambda} \cdot \frac{\pi}{3} = \frac{2\pi}{3}$$

Intensity at point, $P = I_0 \cos^2 \Delta\phi$

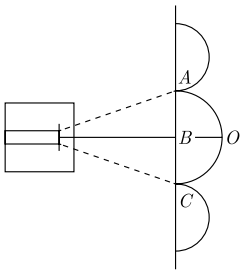
$$= I_0\left[\cos\frac{2\pi}{3}\right]^2 = I_0\left(\frac{1}{2}\right)^2 = \frac{I_0}{4}$$

114. Show that the angular width of the first diffraction fringe is half that of the central fringe.

Ans : **Main 2010**

Let, A and a be the wavelength and slit width of diffracting system respectively.

Let O be the position of central maximum.



Condition for the first minimum is given by

$$d\sin\theta = m\lambda \quad ...(1)$$

Let θ be the angle of diffraction.

As, diffraction angle is small.

$$\sin\theta = \theta$$

For first diffraction minimum,

$$\theta = \theta_1 \quad \text{(let)}$$

NODIA

86. In Young's double slit experiment, what should be the phase difference between the two overlapping waves to obtain 5^{th} dark band/fringe on the screen?

Ans : **Main 2012, 2010**

For dark band path difference

$$\Delta x = (2m-1)\frac{\lambda}{2}$$

Here $m = 5$

$$\Delta x = (2\times 5-1)\frac{\lambda}{2} = 9\lambda/2$$

Phase difference, $\Delta\phi = 2\pi/\lambda \times \Delta x$

$$= 2\pi/\lambda \times 9\lambda/2 = 9\pi$$

87. What happens to fringe width, when the separation between the slits as well as distance of the screen from the slit are halved?

Ans : **Main 2012**

Since fringe width, $\beta = \frac{\lambda D}{d}$

When, $D' = \frac{D}{2}$ and $d' = \frac{d}{2}$ then,

The new fringe width,

$$\beta' = \frac{\lambda D'}{d'}$$

$$= \frac{\lambda D}{2}\times\frac{2}{d}$$

$$= \frac{\lambda D}{d} = \beta$$

i.e. the fringe width remains the same.

88. State the principle of superposition of waves.

Ans : **Comp 2021**

This principle state that when a number of waves travelling through a medium superpose on each other, the resultant displacement at any point at a given instant is equal to the vector sum of the displacement due to the individual waves at that point.

If $\vec{y}_1$, $\vec{y}_2$, $\vec{y}_3$, ..., $\vec{y}_n$ are the displacements due to the different waves acting separately, then according to the principle of superposition, the resultant displacement when all the waves act together is given by the vector sum:

$$\vec{y} = \vec{y}_1 + \vec{y}_2 + \vec{y}_3 + ... + \vec{y}_n$$

89. How will the interference pattern in Young's double slit experiment get affected, when

(i) distance between the slits S_1 and S_2 reduced and

(ii) the entire set up is immersed in water ? Justify your answer in each case.

Ans : **Main 2010**

(i) The fringe width of interference pattern increases with the decrease in separation between S_1S_2 as

$$\beta \propto \frac{1}{d}$$

(ii) The fringe width decrease as wavelength gets reduced when interference set up is taken from air to water.

90. What will happen if Young's double slit experiment is performed in water?

Ans : **Main 2010**

On immersing Young's double slit apparatus in water having index μ, then the wavelength of light λ becomes,

$$\lambda' = \frac{\lambda}{\mu}$$

Since, fringe width β in air,

$$\beta = \frac{\lambda D}{d}$$

So in water, the fringe width β' will be

$$\beta' = \frac{\lambda D}{d} = \frac{\lambda D}{\mu d} = \frac{\beta}{\mu}$$

i.e. the fringe will decrease by a factor $\frac{1}{\mu}$.

91. For a single slit of width a, the first minimum of the interference pattern of a monochromatic light of wavelength λ occurs at an angle of $\frac{\lambda}{a}$. At the same angle of $\frac{\lambda}{a}$, we get a maximum for two narrow slits separated by a distance a. Explain.

Ans : **SQP 2014, 2009**

In diffraction, angular position $\theta = \frac{\Delta x}{a}$ for first minima, $\Delta x = \lambda$

$$\theta = \frac{\lambda}{a}$$

In interference, $d = a$ (given)

and angular position, $\theta = \frac{\Delta x}{d}$

Angular position of first maxima

$(\Delta x = \lambda)$ $\theta = \frac{\lambda}{a}$

92. In Young's double slit experiment, the separation of slits is doubled and the distance of the slits and screen is halved. How will it affect the fringe width?

Ans : **SQP 2013, 2011**

In interference pattern, the fringe width β is given,

$$\beta = \frac{\lambda D}{d} \quad ...(1)$$

Let β' be new fringe width, when

$$d' = 2d$$

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$$I = 4a^2\cos^2\frac{\phi}{2}$$

Hence, Intensity $= 4I_0\cos^2\left(\frac{\phi}{2}\right)$

where $I_0 = a^2$ is the intensity of each harmonic wave at the maxima,

$$\phi = \pm 2n\pi$$

$$\cos^2\frac{\phi}{2} = 1$$

At the maxima,

$$I = 4I_0$$

$= 4 \times$ intensity due to one slit

$$I = 4I_0\cos^2\left(\frac{\phi}{2}\right)$$

For constructive interference, I is maximum.

It is possible when $\cos^2\left(\frac{\phi}{2}\right) = 1; \frac{\phi}{2} = n\pi, \phi = 2\pi n$

For destructive interference, I is minimum, i.e., $I = 0$

It is possible when

$$\cos^2\left(\frac{\phi}{2}\right) = 0$$

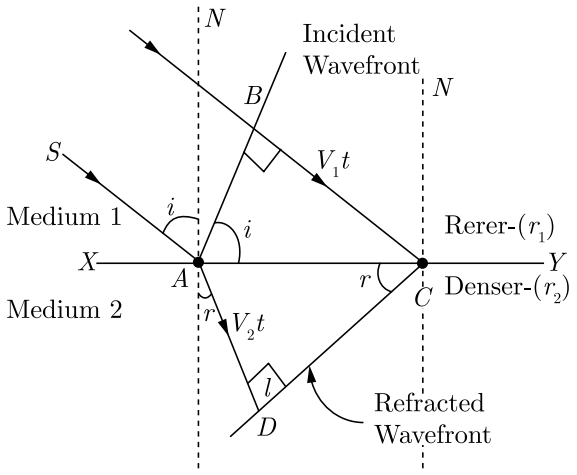
$$\frac{\phi}{2} = \frac{(2n-1)}{2}$$

$$\phi = (2n \pm 1)\frac{\pi}{2}$$

118. Derive Snell's law of refraction using Huygens' wave theory.

Ans : **SPQ 2023, 2022 Sem-II, 2016**

Consider a plane wave front AB incident on a plane surface XY, separating two media 1 and 2 as shown below.



Let v_1 and v_2 be the speeds of light in two media such that $v_2 < v_1$. The wave front first strikes at point A and then at the successive points towards C. According to Huygens' principle, from each point on AC, the secondary wavelets start growing in the second medium with speed v_2. Let the disturbance takes time t to travel from B to C, then $BC = v_1t$. During the times the disturbance from B reaches the point C, the secondary wavelets from point A must have spread over a hemisphere of radius $AD = v_2t$ in the second medium. The tangent plane CD drawn from point C over this hemisphere of radius v_2t will be the new refracted wave front. Let the angles of incidence and refraction be i and r respectively from right.

ΔBAC, $\sin i = \frac{BC}{AC}$,

From right ΔADC, we have,

$$\sin r = \frac{AD}{AC}$$

$$\frac{\sin i}{\sin r} = \frac{BC}{AD} = \frac{v_1t}{v_2t}$$

or $$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = {}_1\mu_2$$

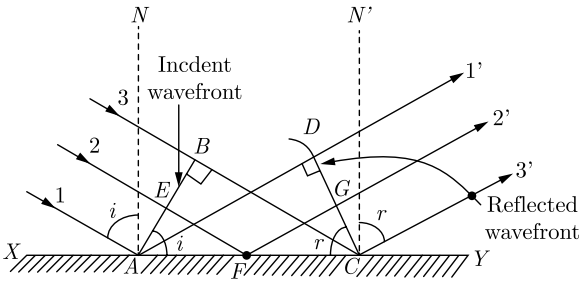
This proves Snell's law of refraction.

119. Using Huygen's wave theory, prove the law of reflection of light.

Ans : **Main 2022 Sem-II, 2019**

Laws of reflection at a plane surface :

Let 1, 2, 3 be the incident rays and 1′, 2′, 3′ be the corresponding reflected rays.



If c is the speed of the light, t is the time taken by light to go from B to C or A to D or E to G through F, then

$$t = \frac{EF}{c} + \frac{FG}{c}$$

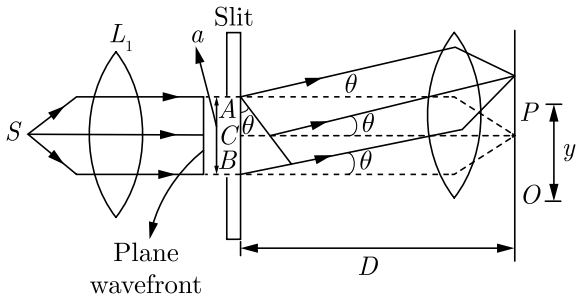
In ΔAEF, $\sin i = \frac{EF}{AF}$

In ΔFGC, $\sin r = \frac{FG}{FC}$

NODIA

107. Using Huygen's construction of secondary wavelets explain how a diffraction pattern is obtained on a screen due to a narrow slit on which a monochromatic beam of light is incident normally.

Ans : **Main 2015**



Consider a parallel beam of light from a lens falling on a slit AB. As, diffraction occurs, the pattern is focused on the screen with the help of lens L_2. We will obtain a diffraction pattern that is central maximum at the centre O, flanked by a number of dark and bright fringes called secondary maxima and minima.

Each point on the plane Wavefront AB sends out the secondary wavelets in all directions. The waves from points equidistant from sthe centre C, lying on the upper and lower half, reach point O with zero path difference and hence, reinforce each other producing maximum intensity at O.

108. Explain why do we need coherent sources to produce interference of light.

Ans : **SQP 2021**

When two monochromatic waves of intensity I_1, I_2 and phase difference ϕ meet at a point, the resultant intensity is given by,

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$$

The last term $2\sqrt{I_1 I_2}\cos\phi$ is called interference term. There are two possibilities:

1. If $\cos\phi$ remains constant with time, the total intensity at any point will be constant. The intensity will be maximum $(\sqrt{I_1}+\sqrt{I_2})^2$ at points where $\cos\phi$ is $+1$ and minimum $(\sqrt{I_1}-\sqrt{I_2})^2$ at points where $\cos\phi = -1$. The sources in this case are coherent.
2. If $\cos\phi$ varies continuously with time, then the interference term averages to zero. There will be same intensity, $I = I_1 + I_2$ at every point i.e., there will be general illumination on the observation screen. The two sources in the case are incoherent.

Hence to observe interference, we need to have two sources with the same frequency and with a stable phase difference. Such a pair of sources are called coherent sources.

109. What will be the effect on interference fringes obtained in Young's double slit experiment if (1) one slit is covered, (2) a source of light of higher wavelength is used, (3) distance between two slits be increased to 1 cm and (4) distance between screen and double slit is increased?

Ans : **SQP 2024**

The fringe width β is given by,

$$\beta = \frac{\lambda D}{d}$$

where, λ is the wavelength of light incident, D is distance between the screen and double slit and d is the distance between the two slits.

1. On covering one slit, the interference pattern will be replaced by diffraction pattern due to single slit.
2. On increasing the wave length of incident light λ, the fringe width will increase.
3. On increasing d by 1 cm, the fringe will disappear and there will be uniform illumination.
4. On increasing D, the fringe width will increase.

110. Two nearby narrow slits are illuminated by a single monochromatic source. Name the pattern obtained on the screen. One of the slits is now covered. What is the name of the pattern now obtained on the screen? Write two differences between the patterns obtained in the two cases.

Ans : **Comp 2019**

When two nearby narrow slits are illuminated by a single monochromatic source of light, we get interference fringes on the screen i.e., we have alternative bright and dark bands.

When one of the slits is covered, we have no interference pattern but have a general illumination on the screen. However, there may be a little diffraction pattern at the edge due to Fraunhoffer's diffraction.

Differences

In first case interference bands are alternative bright and dark bands. All bands are of equal brightness.

In second case diffraction pattern at the edges are not of uniform brightness.

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Then the first two parts will have a path difference of $\frac{\lambda}{2}$ and cancel the effect of each other. The remaining third part will contribute to the intensity at a point between two minima. This is called first secondary maxima. In similar manner we can show that the intensity of the other secondary maxima will go on decreasing.

(ii) For first minima,

$$a\sin\theta = \lambda$$

$$a\theta = \lambda$$

Since, for small angle $\sin\theta \simeq \theta$

$$\tan\theta = \frac{y_1}{D}$$

$$\theta = \frac{y_1}{D}$$

$$\frac{\lambda}{a}D = y_1 = y_2$$

Hence, whole width on secondary maxima on one side is $\frac{\lambda D}{d}$.

The angular width of the central maxima $= \frac{2\lambda D}{a}$

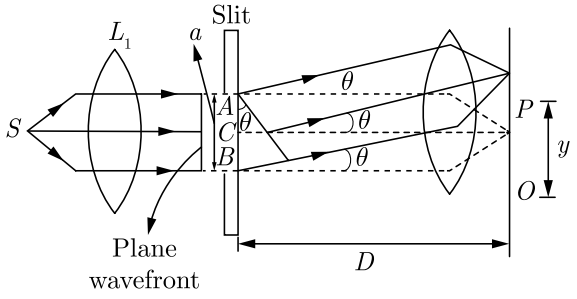
So, angular width of the central maxima is twice that of the first order secondary maximum.

122. Obtain the relation, $d\sin\theta = \lambda$ for the first minima of the diffraction pattern of a single slit of width d using light of wavelength λ.

Ans : **Main 2001**

First we have to find the path difference between the rays reaching on the screen, then apply the condition for maxima or minima.

Consider a point P on the screen at which wavelets travelling in a direction, making an angle θ with CO, are brought to focus by the lens. The wavelets from points A and B will have a path difference equal to BN.



From the right angled ΔANB, we have

$$BN = AB\sin\theta$$

$$BN = d\sin\theta \quad ...(1)$$

Suppose $BN = \lambda$ and $\theta = \theta_1$

Then, the above equation gives

$$\lambda = d\sin\theta_1$$

$$\sin\theta_1 = \frac{\lambda}{d} \quad ...(2)$$

Such a point on the screen will be the position of first secondary minima.

If $BN = 2\lambda$ and $\theta = \theta_2$,

then $2\lambda = d\sin\theta_2$

$$\sin\theta_2 = \frac{2\lambda}{d} \quad ...(3)$$

Such a point on the screen will be the position of second secondary minima.

In general, for nth minima at point P,

$$\sin\theta_n = \frac{n\lambda}{d} \quad ...(4)$$

$$d\sin\theta_n = n\lambda$$

For first minima, $d\sin\theta = \lambda$

where, symbols have their usual meaning.

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123. Use Huygen's principle to show how a plane wavefront propagates from a denser to rarer medium. Hence, verify Snell's law of refraction.

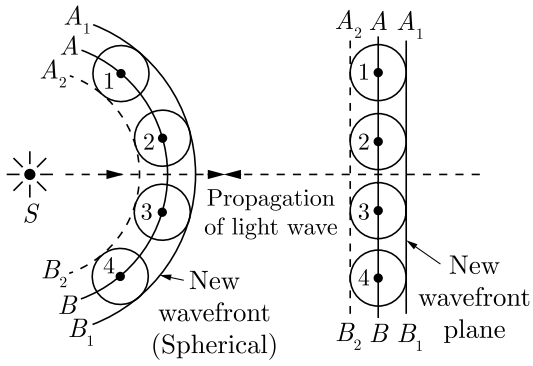
Ans : **Main 2018, 2023**

According to Huygen's principle

(i) Each point on the given wavefront (called primary wavefront) is the source of a secondary disturbance (called secondary wavelets) and the wavelets emanating from these point spread out in all the directions with the speed of the wave.

(ii) A surface touching these secondary wavelets, tangentially in the forward direction at any instant gives the new wave-front at that instant.

This is called secondary wave-front.



(a) (b)

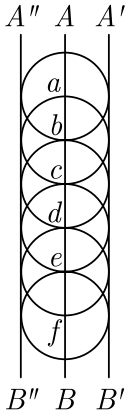
Huygen's Principle

1. Every point of primary wavefront acts as source of secondary wavelets.
2. The common envelope over secondary wavelets gives the formation of secondary wavefront.

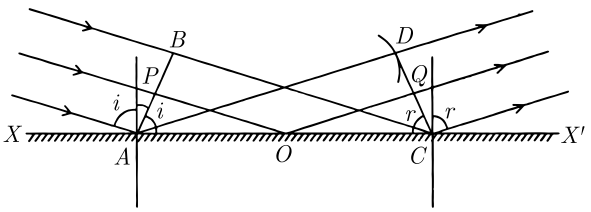
AB - Primary wavefront

$A'B'$ - Forward secondary wavefront

$A''B''$ - Backward secondary wavefront



Laws of Reflection using Huygen's Principle



where, $XX' =$ reflecting surface

$AB =$ incident wavefront

$\angle i =$ incident angle

$CD =$ reflected wavefront

$\angle r =$ reflected angle

$c =$ speed of light

The point P on incident wavefront is reached at Q on reflected wavefront in time t, as taken by point A to reach at D and point B to reach at C.

i.e., $$t = \frac{PO}{c} + \frac{OQ}{c}$$

In ΔAPO, $\sin i = \frac{PO}{AO}$

$$PO = AO\sin i$$

In ΔCQO, $\sin r = \frac{OQ}{OC}$

$$OQ = OC\sin r$$

Hence, $$t = \frac{AO\sin i + OC\sin r}{c}$$

$$= \frac{AO\sin i + AC\sin r - AO\sin r}{c}$$

$$= \frac{AO(\sin i - \sin r) + AC\sin r}{c}$$

AO and AC independent on time, hence we get

$$\sin i - \sin r = 0$$

$$\sin i = \sin r$$

$$\angle i = \angle r$$

1. The incident angle is equal to reflected angle.
2. The incident wavefront, reflected wavefront and normal all lie on same plane.

132. What do you mean by wave front? Write down its type briefly?

Ans : **Main 2020, 2014**

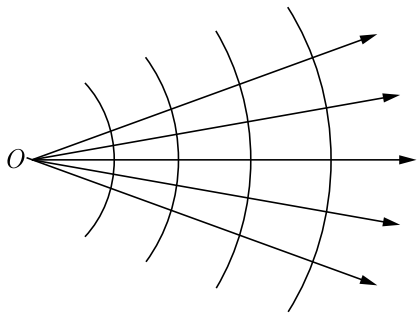
Wave front is defined as the locus of the neighboring particles of the medium which are in the same phase of disturbance.

Wave front are classified in the following types :

1. **Spherical Wave-front :** A wave-front due to point source in a three dimensional isotropic space is called spherical wave-front.

   Consider a point source of light placed in an isotropic medium i.e., a medium in which the velocity of light is the same in all directions. The disturbance from the point source travels equally in all directions.

   If $c =$ velocity of light, then after time t, light will have travelled a distance equal to ct in all directions. The locus of all points where light reaches after time t will be a sphere. A set of spherical wave-front represents a diverging beam of light (Fig. (a)).



(a)

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$$t = \frac{EF}{c} = \frac{FG}{c}$$

In ΔAEF, $\sin i = \frac{EF}{AF}$

In ΔFGC, $\sin r = \frac{FG}{FC}$

or $$t = \frac{AC\sin r + AF(\sin i - \sin r)}{c}$$

$$[FC = AC - AF]$$

For the rays of light from different parts on the incident wave front, the values of AF are different. But light from different points of the incident wave front should take the same time to reach the corresponding points on the reflected wave front. So, t should not depend upon AF. This is possible only if

$$\sin i - \sin r = 0$$

i.e. $$\sin i = \sin r \text{ or } \angle i = \angle r$$

Which is the first law of reflection.

126. Explain diffraction of light due to a narrow single slit and the formation of pattern of fringes on the screen.

Ans : **SQP 2011**

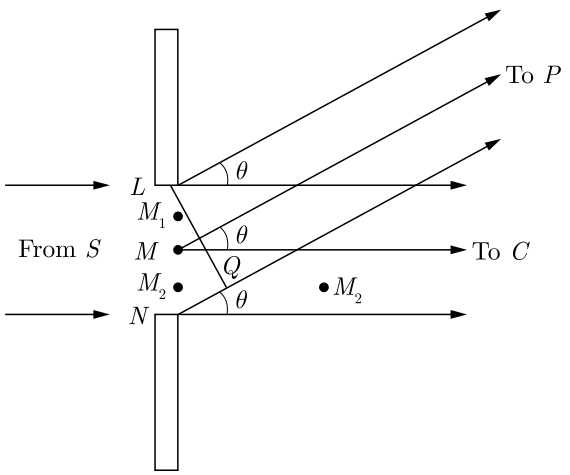
Single slit diffraction is explained by treating different parts of the wave-front at the slit as sources of secondary wavelets.

At the central point C on the screen, θ is zero, All path differences are zero and give maximum intensity at C.

At any other point P, the path difference between two edges of the slit is $NP - LP = NQ$

$$= a\sin\theta \simeq a\theta$$

Any point P, in direction θ, is a location of minima if $a\theta = n\lambda$



This can be explained by dividing the slit into even number of parts. The path difference between waves from successive parts is 180° out of phase and hence cancel each other leading to a minima. Any point P, in direction Q, is a location of maxima if $a\theta = (n + \frac{1}{2})\lambda$

This can be explained by dividing the slit into odd number of parts. The contributions from successive parts cancel in pairs because of 180° phase difference. The unpaired part produce intensity at P, leading to a minima.

127. Show that the central maximum in the single slit diffraction is twice as wide as the second maxima and the pattern becomes narrow as the width of sit is increased.

Ans : **Comp 2025**

Width of central maxima is the distance between first secondary minimum on either side of central point in front of slit.

Hence, $d\sin\theta = 1\lambda$ for first secondary minima

or $$\sin\theta = \frac{\lambda}{d}$$

If f is the focal length of the focussing lens (on screen side), held close to the slit, then D, the distance of slit from the screen is equal to f i.e.,

$$D = f$$

Hence, $$\sin\theta \approx \theta = \frac{y}{f} = \frac{y}{D}$$

$$\frac{y}{D} = \frac{\lambda}{d}$$

$$y = \frac{D\lambda}{d}$$

Since θ is half the angular width of central maxima of single slit,

Hence, Width of central maxima

$$= 2y = \frac{2D\lambda}{d} = \frac{2f}{d} \quad ...(1)$$

Width of secondary maxima is the distance between nth and $(n+1)$th maxima.

We know for a nth minima

$$d\sin\theta_n = n\lambda$$

$$\sin\theta_n = \frac{n\lambda}{d}$$

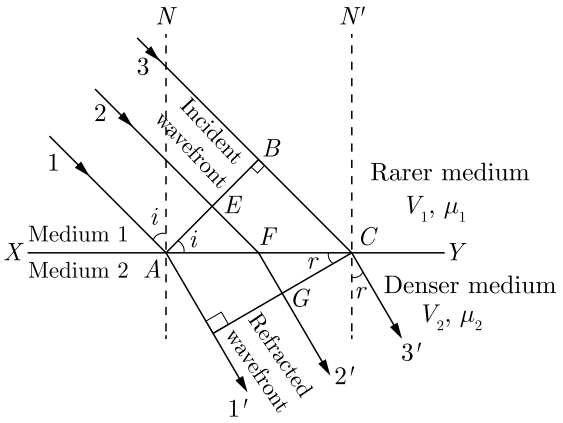
and $$\sin\theta_{n+1} = (n+1)\frac{\lambda}{d}$$

Hence,

$$\sin\theta_{n+1} - \sin\theta_n = [n + 1 - n]\frac{\lambda}{d} = \frac{\lambda}{d}$$

NODIA

Propagation of wave front



If v_1, v_2 are the speed of light into two mediums and t is the time taken by light to go from B to C or A to D or E to G through F, then

$$t = \frac{EF}{v_1} + \frac{FG}{v_2}$$

In ΔAFE, $\sin i = \frac{EF}{AF}$

In ΔFGC, $\sin r = \frac{FG}{FC}$

$$t = \frac{AF \sin i}{v_1} + \frac{FC \sin r}{v_2}$$

$$t = \frac{AC \sin r}{v_2} + AF\left(\frac{\sin i}{v_1} - \frac{\sin r}{v_2}\right)$$

For rays of light from the different part on the incident wave-front, the values of AF are different. But light from different points of the incident wavefront should take the same time to reach the corresponding points on the refracted wavefront.

So, t should not depend on F. This is possible only, if

$$\frac{\sin i}{v_1} - \frac{\sin r}{v_2} = 0$$

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \mu$$

Now, if c represents the speed of light in vacuum, then $\mu_1 = \frac{c}{v_1}$ and $\mu_2 = \frac{c}{v_2}$ are known as the refractive index of medium 1 and medium 2 respectively.

Then, $\mu_1 \sin i = \mu_2 \sin r$

$$\mu = \frac{\sin i}{\sin r}$$

This is known as Snell's law of refraction.

FOUR MARKS QUESTIONS

124. Compare and contrast the pattern which is seen with two coherently illuminated narrow slits in Young's experiment with that seen for a coherently illuminated single slit producing diffraction.

Ans : SQP 2008

Comparison between two Slit Young's Interference pattern and Single slit diffraction pattern : Both patterns are the result of wave nature of light; both patterns contain maxima and minima. Interference pattern is the result of superposing two coherent wave while the diffraction pattern is the superposition of large number of waves originating from each point on a single slit.

Differences :

(i) In Young's two slit experiment; all maxima are of same intensity while in diffraction at a single slit, the intensity of central maximum is maximum and it falls rapidly for first, second order secondary maxima on either side of it.

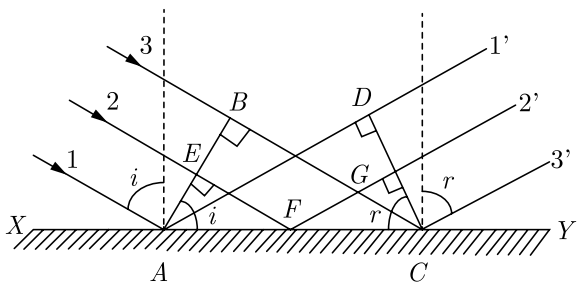
(ii) In Young's interference the fringes are of equal width while in diffraction at a single slit, the central maximum is twice as wide as wide as other maxima. The intensity falls as we go to successive maxima away from the centre on either side.

(iii) In a single slit diffraction pattern of width a, the first minimum occurs at $\frac{\lambda}{a}$; while in two slit interference pattern of slit separation a, we get maximum at the same angle $\frac{\lambda}{a}$.

125. On the basis of Huygens' wave theory of light, show that the angle of reflection is equal to angle of incidence. You must draw a labelled diagram for this derivation.

Ans : Main 2023, 2015

Let 1, 2, 3 be the incident rays and 1′, 2′, 3′ be the corresponding reflected rays.



If c is the speed of the light, t is the time taken by light to go B to C or A to D or E to G through F, then

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$$= \left[D^2 + \left(y + \frac{d}{2}\right)^2\right]^{1/2} - \left[D^2 + \left(y - \frac{d}{2}\right)\right]^{1/2}$$

$$= D\left[1 + \frac{(y + d/2)^2}{D^2}\right]^{1/2} - D\left[1 + \frac{(y - d/2)^2}{D^2}\right]^{1/2}$$

$$= D\left[1 + \frac{(y + d/2)^2}{2D^2}\right] - D\left[1 + \frac{(y - d/2)^2}{2D^2}\right]$$

$$= D\left[1 + \frac{(y + d/2)^2}{2D^2} - 1 - \frac{(y - d/2)^2}{2D^2}\right]$$

$$= \frac{D}{2D^2}\left[y^2 + \frac{d^2}{4} + \frac{2yd}{2} - y^2 - \frac{d^2}{4} + \frac{2yd}{2}\right]$$

$$= \frac{1}{2D}[2yd] = \frac{dy}{D}$$

$$S_2P - S_1P \approx \frac{dy}{D}$$

For constructive interference (Bright fringes)

$$\text{Path difference} = \frac{dy}{D} = n\lambda,$$

where, $n = 0, 1, 2, 3, \ldots$

$$y = \frac{nD\lambda}{d}$$

Hence, for $n = 0$, $y_0 = 0$ at O (central bright fringe)

For $n = 1$, $y_1 = \frac{D\lambda}{d}$ (for 1st bright fringe)

For $n = 2$, $y_2 = \frac{2D\lambda}{d}$ (for 2nd bright fringe)

For $n = n$, $y_n = \frac{nD\lambda}{d}$ (nth bright fringe)

The separation between two consecutive bright fringes is equal to fringe width given as

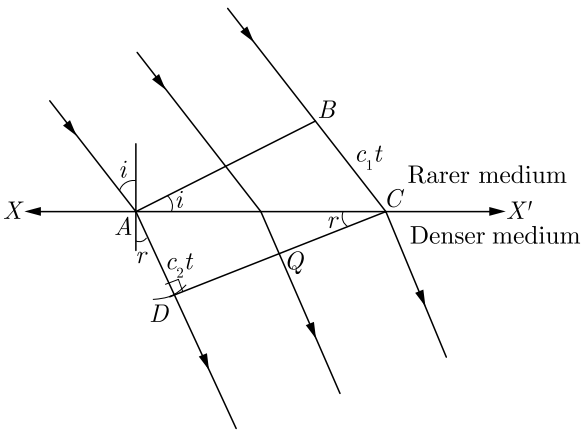
$$\beta = y_n - y_{n-1}$$

$$= \frac{nD\lambda}{d} - \frac{(n-1)D\lambda}{d} = \frac{D\lambda}{d}$$

130. How are wavefront and secondary wavelets defined? Verify laws of reflection or laws of refraction on the basis of Huygen's wave theory.

Ans : **Main 2021**

Laws of Refracting using Huygen's Principle



where, XX' = two media separating surface

AB = incident wavefront

CD = refracted wavefront

$\angle i$ = incident angle

$\angle r$ = refracted angle

c_1 = speed of light in rarer medium

c_2 = speed of light in denser medium

The point P on incident wavefront is reached at Q on refracted wavefront in time t as taken by point B to reach at C and point A to reach at D.

i.e., $$t = \frac{PO}{c_1} + \frac{OQ}{c_2}$$

In ΔAPO, $\sin i = \frac{PO}{AO}$

$$PO = AO\sin i$$

In ΔCQO, $\sin r = \frac{OQ}{OC}$

$$OQ = OC\sin r$$

Hence, $$t = \frac{AO\sin i}{c_1} + \frac{OC\sin r}{c_2}$$

$$= \frac{AO\sin i}{c_1} + \frac{(AC - AO)\sin r}{c_2}$$

$$= AO\left(\frac{\sin i}{c_1} - \frac{\sin r}{c_2}\right) + \frac{AC\sin r}{c_2}$$

AO and AC independent on time, hence we get

$$\frac{\sin i}{c_1} - \frac{\sin r}{c_2} = 0$$

$$\frac{\sin i}{c_1} = \frac{\sin r}{c_2}$$

$$\frac{c_1}{c_2} = \frac{\sin i}{\sin r}$$

The ratio of speed of light in rarer medium to denser medium is called refractive index of optical medium.

i.e., $$\mu = \frac{c_1}{c_2}$$

Hence, $$\mu = \frac{\sin i}{\sin r}$$

This is Snell's law.

131. Explain Huygens principle of secondary wavelets and on the basis of this principle establish the law of Refraction 'OR' reflection.

Ans : **SQP 2021**

Wavefront

A wavefront is defined as the continuous locus of all such particles of the medium which are vibrating in the same phase at any instant.

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Since angles are small,

$$\sin\theta \approx \theta$$

$$\theta_{n+1} - \theta_n = \frac{\lambda}{d}$$

$$\Delta\theta_n = \frac{\lambda}{d}$$

$$\frac{y}{D} = \frac{\lambda}{d} \qquad ...(2)$$

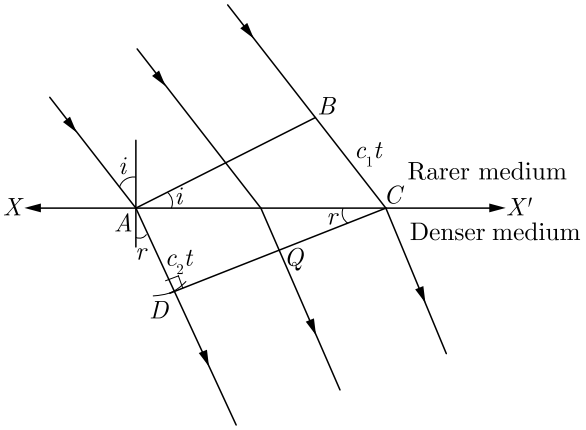
Thus we find that equation (1) is twice the equation (2) showing there by that the central maxima is twice any secondary maxima.

If the width of slit is increased then as y decreases which shows that pattern will become narrower as the width of the slit is increased.

128. On the basis of Huygens' wave theory, prove Snell's law of refraction of light. Draw a neat and labelled diagram.

Ans : **Main 2012, 2005, 2002, 2000**

Laws of Refracting using Huygen's Principle



where, XX' = two media separating surface

AB = incident wave-front

CD = refracted wave-front

$\angle i$ = incident angle

$\angle r$ = refracted angle

c_1 = speed of light in rarer medium

c_2 = speed of light in denser medium

The point P on incident wave-front is reached at Q on refracted wave-front in time t as taken by point B to reach at C and point A to reach at D.

i.e., $$t = \frac{PO}{c_1} + \frac{OQ}{c_2}$$

In ΔAPO, $\sin i = \frac{PO}{AO}$

$$PO = AO\sin i$$

In ΔCQO, $\sin r = \frac{OQ}{OC}$

$$OQ = OC\sin r$$

Hence, $$t = \frac{AO\sin i}{c_1} + \frac{OC\sin r}{c_2}$$

$$= \frac{AO\sin i}{c_1} + \frac{(AC - AO)\sin r}{c_2}$$

$$= AO\left(\frac{\sin i}{c_1} - \frac{\sin r}{c_2}\right) + \frac{AC\sin r}{c_2}$$

AO and AC independent on time, hence we get

$$\frac{\sin i}{c_1} - \frac{\sin r}{c_2} = 0$$

$$\frac{\sin i}{c_1} = \frac{\sin r}{c_2}$$

$$\frac{c_1}{c_2} = \frac{\sin i}{\sin r}$$

The ratio of speed of light in rarer medium to denser medium is called refractive index of optical medium.

i.e., $$\mu = \frac{c_1}{c_2}$$

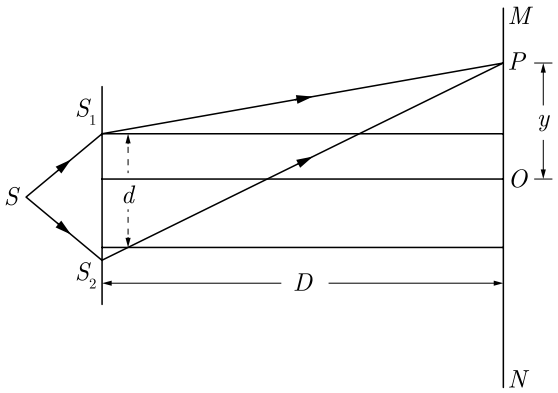
Hence, $$\mu = \frac{\sin i}{\sin r}$$

This is Snell's law.

129. Draw a neat labelled diagram of Young's double slit experiment. Show that $\beta = \lambda D/d$, where the terms have their usual meaning (either for bright or dark fringe).

Ans : **Main 2019, 2014**

Young's Double Slit Experiment Suppose S_1 and S_2 are two fine slits, a small distance d apart. They are illuminated by a strong source S of monochromatic light of wavelength λ. MN is a screen at a distance D from the slits.



Consider a point P at a distance y from O, the centre of screen.

The path difference between two waves arriving at point P is equal to $S_2P - S_1P$.

Now, $S_2P - S_1P$

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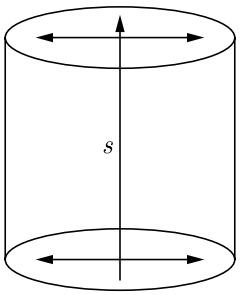
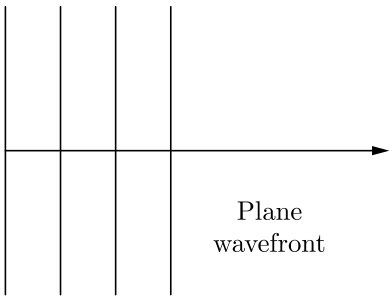
2. **Cylindrical Wave-front :** When the slit is a source of light, all points equidistant from the source, lie on a cylinder. Therefore, wave-front is cylindrical (Fig. (b)).



(b)

3. **Plane Wave-front :** When the source is at infinite distance, the radius of curvature of wave-front will be very large.

   A small portion of spherical wave-front with source at infinite distance is a plane wave-front. (Fig. (c)).



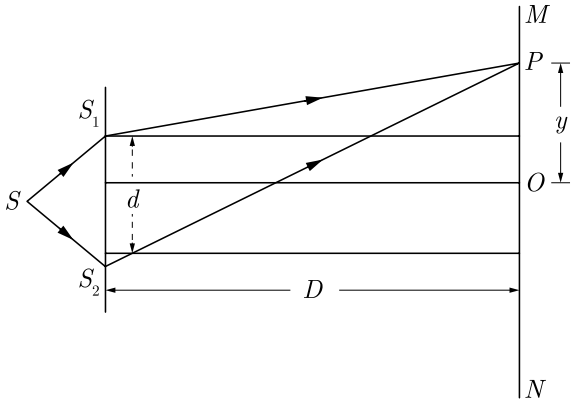
(c)

133. Draw a neat and labelled diagram of an experimental set-up of Young's double slit experiment to study the interference of light and show that $\beta = \frac{\lambda D}{d}$

where, the terms have their usual meaning. Show intensity variation in the interference.

Ans : **Main 2016, 2007**

Young's Double Slit Experiment : Suppose S_1 and S_2 are two fine slits, a small distance d apart. They are illuminated by a strong source S of monochromatic light of wavelength λ. MN is a screen at a distance D from the slits.



Consider a point P at a distance y from 0, the centre of screen.

The path difference between two waves arriving at point P is equal to $S_2P - S_1P$.

Now,

$$(S_2P)^2 - (S_1P)^2 = \left[D^2 + \left(y + \frac{d}{2}\right)^2\right] - \left[D^2 + \left(y - \frac{d}{2}\right)^2\right]$$

$$= 2yd$$

Thus, $$S_2P - S_1P = \frac{2yd}{S_2p \cdot S_1p}$$

But $$S_2P + S_1P \approx 2D$$

$$S_2P - S_1P \approx \frac{dy}{D}$$

For constructive interference (Bright fringes)

$$\text{Path difference} = \frac{dy}{D} = n\lambda,$$

where, $n = 0, 1, 2, 3, ...$

$$y = \frac{nD\lambda}{d} \qquad [n = 0,1,2,3,...]$$

Hence, for $n = 0$, $y_0 = 0$ at O (central bright fringe) The separation between two consecutive bright fringes

$$\beta = \frac{nD\lambda}{d} - \frac{(n-1)D\lambda}{d} = \frac{D\lambda}{d}$$

For destructive interference (Dark fringes)

$$\text{Path difference} = \frac{dy}{D} - (2n-1)\frac{\lambda}{2}$$

or

$$y = (2n-1)\frac{D\lambda}{2d},$$

where $n = 1, 2, 3,...$

The separation between two consecutive dark fringes is

$$\beta = (2n-1)\frac{D\lambda}{2d}\{2(n-1)-1\}\frac{D\lambda}{2d}$$

$$= \frac{D\lambda}{d}$$

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The distance between two consecutive bright or dark fringes is called fringe width β.

Fringe width, $\beta = \frac{D\lambda}{d}$

Intensity of the fringes,

$$I_R = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$$

For a bright fringe,

$$\phi = 2n\pi$$

and $\cos 2n\pi = 1$

So, $I_R = I_{\max} = I_1 + I_2 + 2\sqrt{I_1 I_2} = 4I$

(as, $I_1 = I_2 = I$ in YDSE)

Intensity of a bright fringe $= 4I$

and for a dark fringe,

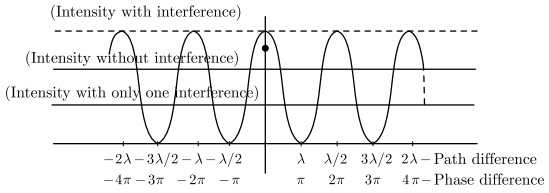
$$\phi = (2n-1)\pi$$

$$\cos\phi = -1$$

So, $I_R = I_{\min} = I_1 + I_2 - 2\sqrt{I_1 I_2} = 0$

Intensity of a dark fringe $= 0$

Distribution of Intensity : The distribution of intensity in Young's double slit experiment is shown below.


(Intensity with interference)
(Intensity without interference)
(Intensity with only one interference)
−2λ −3λ/2 −λ −λ/2 λ λ/2 3λ/2 2λ − Path difference
−4π −3π −2π −π π 2π 3π 4π − Phase difference

134. What are coherent sources of light? Draw the variation of intensity with position in the interference of Young's double slit experiment.

Ans : **Comp 2024**

Coherent sources are those sources which emit continuously light of same wavelength and magnitude either in the same phase or with a constant phase difference.

Let the waves of two coherent sources be,

$$y_1 = a\sin\omega t$$

and $y_2 = b\sin(\omega t + \phi)$

where, a and b are the respective amplitudes of the two waves and ϕ is the constant phase angle by which the second wave leads the first wave. [Figure (a)]

According to superposition principle, the displacement y of resultant wave is

$$y = y_1 + y_2 = a\sin\omega t + b\sin(\omega t + \phi)$$

$$= a\sin\omega t + b\sin\omega t\cos\phi + b\cos\omega t\sin\phi$$

$$= \sin\omega t(a + b\cos\phi) + \cos\omega t \cdot b\sin\phi$$

Substituting, $a + b\cos\phi = A\cos\theta$ ...(1)

and $b\sin\phi = A\sin\theta$ ...(2)

We have, $y = \sin\omega t \cdot A\cos\theta + \cos\omega t \cdot A\sin\theta$

$$= A\sin(\omega t + \theta)$$

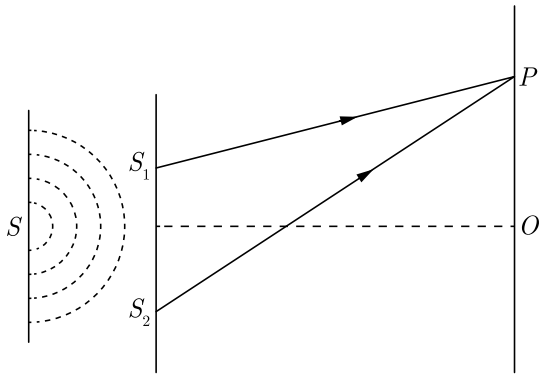
where, A is the amplitude of the resultant wave.

Squaring and adding (1) and (2), we have

$$a^2 + b^2\cos^2\phi + 2ab\cos\phi + b^2\sin^2\phi = A^2\cos^2\theta + A^2\sin^2\theta$$

$$a^2 + b^2(\cos^2\phi + \sin\phi) + 2ab\cos\phi = A^2(\cos^2\theta + \sin^2\theta)$$

$$A^2 = a^2 + b^2 + 2ab\cos\phi$$



(a)

Since resultant intensity is proportional to square of amplitude,

Hence, $I \propto A^2$

$$I \propto (a^2 + b^2 + 2ab\cos\phi)$$

$$I = a^2 + b^2 + 2ab\cos\phi \quad ...(3)$$

(For convenience, we assume that intensity of light is equal to square of amplitude)

1. For constructive interference (or for maximum).

   I should be maximum

   i.e., $\cos\phi = 1$

   and $I_{\max} = (a+b)^2$

   $$\phi = 0,\ 2\pi,\ 4\pi$$

   $$\phi = 2\pi n$$

   Path diff. $\frac{\lambda}{2\pi}\phi = \frac{\lambda}{2\pi}2\pi n = n\lambda$ ...(4)

   So, for constructive interference (or for maximum intensity), path difference should be integral multiple of λ.

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2. For destructive interference (or for minima) I should be minima

i.e. $\cos\phi = -1$

and $I_{min} = (a-b)^2$

$\phi = \pi, 3\pi, 5\pi, ...$

$\phi = (2n+1)\pi$

(where, $n = 0,1,2,...$)

Path difference $= \frac{\lambda}{2\pi}(2n+1)\pi$

$= (2n+1)\frac{\lambda}{2}$ ...(5)

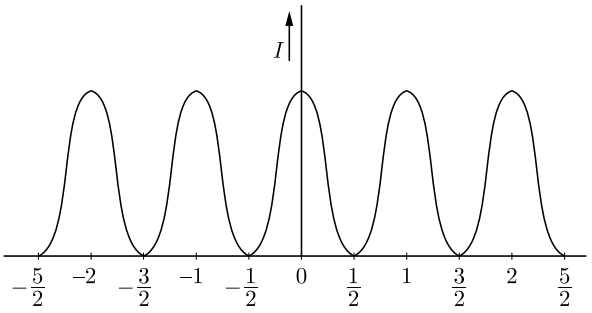
So, for destructive interference (or for minimum intensity), path difference should be an odd multiple of $\frac{\lambda}{2}$.

Variation of Intensity with Position

From above discussion, we find that intensity of light is maximum when path difference is $n\lambda$ i.e. $\pm\lambda, 2\lambda, 3\lambda$ ... and minimum when path difference is $(2n+1)\frac{\lambda}{2}$

i.e. $\pm\frac{\lambda}{2}, 3\frac{\lambda}{2}, 5\frac{\lambda}{2}$, ...

The variation in intensity of light with position in interference is as shown in Figure (b).



(b)

135. What is diffraction and explain diffraction at a single slit?

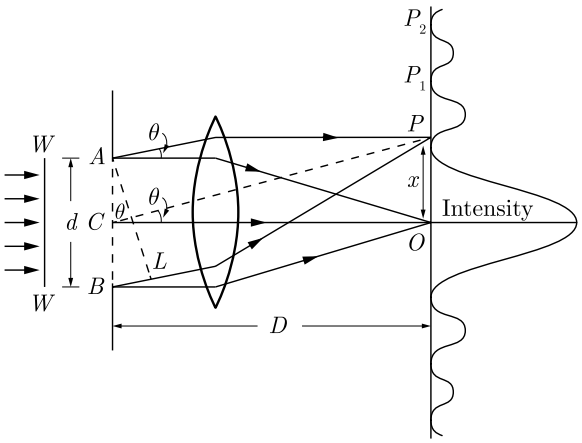
Ans : **Main 2019, 2011**

Diffraction : Is the phenomenon of bending of light around the corner of an obstacle or aperture.

Diffraction of Light by Narrow Slit : Consider a narrow slit AB perpendicular to plane of paper on which a monochromatic light be incident normally. Due to diffraction pattern consists of a central band much wider than the slit width just opposite to the slit and bordered on either side by dark and bright fringes of decreasing intensity. It is found that,

(i) The intensity of the secondary maxima goes on decreasing.

(ii) The width of central maximum is double that of a secondary maximum.



Consider a plane wave-front WW incident on the slit AB as shown in the Figure Imagine the slit to be divided into a large number of very narrow strips of equal width parallel to the slit. When the wave-front reaches the slit, each narrow strip parallel to the slit can be considered to be a source of Huygen's secondary wavelets.

Central Maxima

Let us first consider the effect of all the wavelets at the point O just opposite to the middle of the slit. Since distance between the slit and the screen is very large with the width of the slit, the wavelets covers the same distance and reach O in the same phase. Thus the wavelets reinforce each other's effect to give maximum intensity at O.

Let us now consider the intensity at a point P above O produced by the rays travelling at an $\angle\theta$ with the original direction. Since the width of the slit is very small, all the rays reaching P proceed almond parallel to each other. The wavelets from all the points in the slit start in the same phase but as the travel different distances, they reach P n different phases. Draw AL normal to BP.

The path difference between the extreme rays is,

$$BP - AP = BL$$

Let, C be the mid-point of slit or path difference between AP and $CP = \frac{\lambda}{2}$

Hence, Wavelets starting from A and C shall reach the point P in opposite phases and cancel each other effect.

Similarly, the wavelets from a strip below A are cancelled by the wavelets from a corresponding strip below C.

In ΔABL, $\frac{BL}{AB} = \sin\theta$

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Hence, $BL = AB\sin\theta$

$BL = d\sin\theta$

For first minima, $BL = \lambda$;

Hence, $d\sin\theta = \lambda,\ \sin\theta = \frac{\lambda}{d}$

Since θ is small.

Hence, $\sin\theta = \theta = \frac{x}{D}$

$\frac{x}{D} = \theta = \frac{\lambda}{d}$

or $x = \frac{D}{d}\lambda$

At a point slightly above P i.e. P_1, the path difference between the two rays in BL_1.

If, $BL_1 = \frac{3}{2}\lambda$

Then slit AB can be divided into three equal parts as shown in the figure The waves from corresponding points AC_1 and C_1C_2 cancel each other. The waves from C_2B produce secondary maximum at an angle θ_1 given by,

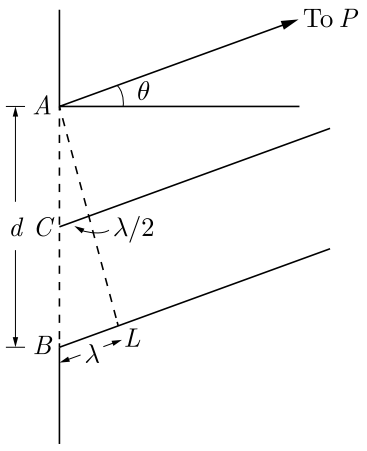
$d\sin\theta_1 = \frac{3}{2}\lambda$

$\sin\theta_1 = \frac{3}{2}\frac{\lambda}{d}$

If θ_1 is small then $\sin\theta_1 = \theta_1$

$\theta_1 = \frac{3}{2}\frac{\lambda}{d}$

A another point P_2, figure (c), the path difference between two rays is $BL_2 = 2\lambda$, then, the slit AB can be supposed to be divided into four equal parts. The waves from corresponding points of the parts AC_1 and C_1C_3 cancel each other. Also the waves from the corresponding points C_2C_3 and C_3B cancel each other producing second minima at angle θ_2 given by,



(a)

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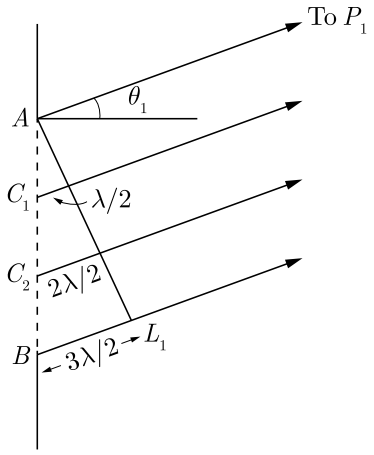
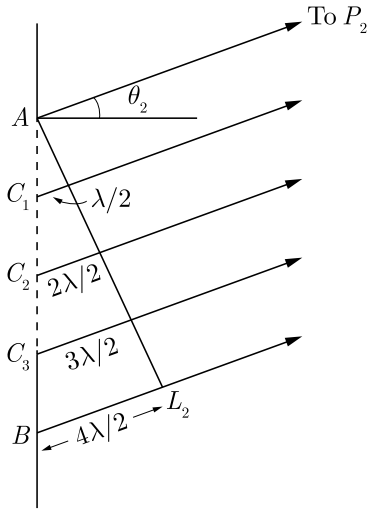


(b)



(c)

$BL_2 = d\sin\theta_2 = 2\lambda$

$\sin\theta_2 = \frac{2\lambda}{d}$

$\theta_2 = \frac{2\lambda}{d}$ provided θ_2 is small.

In general, the various minima occur if the path difference between extreme rays is even multiple of $\frac{\lambda}{2}$.

i.e., $d\sin\theta_n = \frac{2n\lambda}{2} = n\lambda$

$\sin\theta_n = \frac{n\lambda}{d}$

$\frac{x}{D} = \theta_n = \frac{n\lambda}{d}$

(As, θ_n is very small, $\sin\theta_n \approx \theta_n$)

The intensity of central fringes is maximum whereas that of other fringes falls off rapidly in either direction from the centre of the fringe pattern.

136. In Young's double slit experiment, deduce the conditions for (i) constructive and (ii) destructive interference at a point on the screen. Draw a graph showing variation of the resultant intensity in the interference pattern against position X on the screen.

Ans : **Comp 2012, 2016**

Conditions of Constructive and Destructive Interference : When two difference travel in the same direction along a straight line simultaneously, they superpose in such a way that the intensity of the resultant wave is maximum at certain points and minimum at certain other points. The phenomenon of redistribution of intensity due to superposition of two waves of same frequency and constant initial phase difference is called the interference. The waves of same frequency and constant initial phase difference are called coherent waves. At points of medium where the waves arrive in the same phase, the resultant intensity is maximum and the interference at these points is said to be constructive. On the other hand, at points of medium where the waves arrive in opposite phase, the resultant intensity is minimum and the interference at these points is said to be destructive. The positions of maximum intensity are called maxima while those of minimum intensity are called minima. The interference takes place in sound and light both.

Mathematical Analysis : Suppose two coherent waves travel in the same direction along a straight line, the frequency of each wave is $\frac{\omega}{2\pi}$ and amplitudes of electric field are a_1 and a_2 respectively. If at any time t, the electric fields of waves at a point are y_1 and y_2 respectively and phase difference is ϕ, then equation of waves may be expressed as

$$y_1 = a_1 \sin \omega t \quad ...(1)$$

$$y_2 = a_2 \sin(\omega t + \phi) \quad ...(2)$$

According to Young's principle of superposition, the resultant displacement at that point will be

$$y = y_1 + y_2 \quad ...(3)$$

Substituting values of y_1 and y_2 from (1) and (2) in (3), we get

$$y = a_1 \sin \omega t + a_2 \sin(\omega t + \phi)$$

Using trigonometric relation,

$$\sin(\omega t + \phi) = \sin \omega t \cos \phi + \cos \omega t \sin \phi$$

$$y = a_1 \sin \omega t + a_2(\sin \omega t \cos \phi + \cos \omega t \sin \phi)$$

$$= (a_1 + a_2 \cos \phi) \sin \omega t + (a_2 \sin \phi) \cos \omega t \quad ...(4)$$

Let, $a_1 + a_2 \cos \phi = A \cos \theta \quad ...(5)$

and $a_2 \sin \phi = A \sin \theta \quad ...(6)$

Where A and θ are new constants

Then equation (4) gives

$$y = A \cos \theta \sin \omega t + A \sin \theta \cos \omega t$$

$$= A \sin(\omega t + \theta) \quad ...(7)$$

This is equations of the resultant disturbance. Clearly the amplitude of resultants disturbance is A and phase difference from first wave is θ. The values of A and θ are determined by (5) and (6). Squaring (5) and (6) and then adding, we get

$$(a_1 + a_2 \cos \phi)^2 + (a_2 \sin \phi)^2 = A^2 \cos^2 \theta + A^2 \sin \theta$$

$$a_1^2 + a_2^2 \cos^2 \phi + 2a_1 a_2 \cos \phi + a_2^2 \sin^2 \phi = A^2(\cos^2 \theta + \sin^2 \theta)$$

As, $\cos^2 \theta + \sin^2 \theta = 1$, we get

$$A^2 = a_1^2 + a_2^2(\cos^2 \phi + \sin^2 \phi) + 2a_1 a_2 \cos \phi$$

$$A^2 = a_1^2 + a_2^2 + 2a_1 a_2 \cos \phi$$

Amplitude,

$$A = \sqrt{a_1^2 + a_2^2 + 2a_1 a_2 \cos \phi} \quad ...(8)$$

As the intensity of a wave is proportional to its amplitude in arbitrary units $I = A^2$

Intensity of resultant wave,

$$I = A^2 = a_1^2 + a_2^2 + 2a_1 a_2 \cos \phi \quad ...(9)$$

Clearly the intensity of resultant wave at any point depends on the amplitudes of individual waves and the phase difference between the waves at the point.

Constructive Interference : For maximum intensity at any point $\cos \phi = +1$

or phase difference $\phi = 0, 2\pi, 4\pi, 6\pi ...$

$$= 2n\pi (n = 0, 1, 2 ...) \quad ...(10)$$

The maximum intensity,

$$I_{max} = a_1^2 + a_2^2 + 2a_1 a_2$$

$$= (a_1 + a_2)^2 \quad ...(11)$$

Path difference, $\Delta = \frac{\lambda}{2\pi} \times$ Phase difference

$$= \frac{\lambda}{2\pi} \times 2n\pi = n\lambda \quad ...(12)$$

Clearly, the maximum intensity is obtained in the region of superposition at those points where waves meet in the same phase or the phase difference between the waves is even multiple of π or path difference between them is the integral multiple of λ and maximum intensity is $(a_1 + a_2)^2$ which is greater than the sum intensities of individual waves by an amount $2a_1 a_2$.

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149. In Young's double-slit experiment, the angular width of fringe formed on a distance screen is 0.1°. If wavelength of light is $6000\,\mathring{\text{A}}$. What is the spacing between the slits?

Ans : SQP 2008

Angular width of fringe,

$$\theta = 0.1^\circ$$
$$= 1.745 \times 10^{-3} \text{ rad}$$

Wavelength of light,

$$\lambda = 6000\,\mathring{\text{A}} = 6000 \times 10^{-3}\text{m}$$

Spacing between the slits,

$$d = \frac{\lambda}{\theta} = \frac{6000 \times 10^{-10}}{1.745 \times 10^{-3}}$$
$$= 3.4 \times 10^{-4}\text{m}$$

150. In double slit experiment using light of wavelength 600 nm, the angular width of a fringe formed on a distant screen is 0.1°. What is the spacing between the two slits ?

Ans : SQP 2021

Wavelength of light,

$$\lambda = 600\,\text{nm} = 600 \times 10^{-9}\,\text{m}$$

Angular width of fringe

$$\theta = 0.1^\circ = \frac{0.1\pi}{180}\,\text{rad}$$

Using the formulae, $\theta = \frac{\lambda}{d}$

Spacing between the slits,

$$d = \frac{\lambda}{\theta} = \frac{600 \times 10^{-9} \times 180}{0.1 \times \pi}$$
$$d = 3.44 \times 10^{-4}\,\text{m}$$

Thus, the spacing between the two slits is $3.44 \times 10^{-4}\,\text{m}$.

151. When one of the slits of Young's experiment is covered with a transparent sheet of thickness 4.8 mm, the central fringe shifts to a position originally occupied by the 30th bright fringe. What should be the thickness of the sheet, if the central fringe has to shift to the position occupied by 20th bright fringe?

Ans : Main 2020

Initial thickness of sheet,

$$t_1 = 4.8 \text{ mm}$$

Initial no. of central bright fringes,

$$n_1 = 30$$

And final number of central bright fringe,

$$n_2 = 20$$

Final thickness of the sheet,

$$t_2 = \frac{n_2}{n_1} \times t_1$$
$$= \frac{20}{30} \times 4.8 = 3.2\,\text{mm}$$

152. Calculate the angular width of the central maxima obtained in Fraunhofer single slit diffraction experiment, when a monochromatic light of wavelength 550 nm falls normally on a rectangular slit of width 1.1×10^{-4} cm.

Ans : SQP 2023

$$\lambda = 550\,\text{nm} = 550 \times 10^{-9}\,\text{m}$$
$$d = 1.1 \times 10^{-4}\,\text{cm} = 11 \times 10^{-6}\,\text{m}$$

$$\text{Angular width} = \frac{2\lambda}{d}$$
$$= \frac{2 \times 550 \times 10^{-9}\,\text{m}}{11 \times 10^{-6}\,\text{m}}$$
$$= \frac{2 \times 550 \times 10^{-9} \times 10^{6}}{11}$$
$$= 0.1\,\text{m} = 10\,\text{cm}$$

153. Two plane mono-chromic waves propagating in the same direction with amplitudes A and $2A$ and differing in phase by $\frac{\pi}{3}$ superpose. Calculate the amplitude of the resultant wave.

Ans : Main 2024

Given, $A_1 = A$

$$A_2 = 2A$$
$$\phi = \frac{\pi}{3}$$

Hence, $A_R = \sqrt{A_1^2 + A_2^2 + 2A_1A_2\cos\phi}$

$$= \sqrt{A^2 + (2A)^2 + 2A \times 2A\cos\frac{\pi}{3}}$$
$$= \sqrt{5A^2 + 4A^2 \times \frac{1}{2}}$$
$$= 7A^2 = \sqrt{7}\,A$$

154. Monochromatic light of wavelength 650 nm falls normally on a slit of width 1.3×10^{-4} cm and the resulting Fraunhofer diffraction is obtained on a screen. Find the angular width of the central maxima.

Ans : Main 2016

In single slit diffraction, first minimum occurs at

$$d\sin\theta = \lambda \text{ or } \sin\theta = \frac{\lambda}{d}$$

as $\lambda << d$ so, $\theta = \frac{\lambda}{d}$ $\quad (\sin\theta = \theta)$

NODIA

142. Two coherent sources have intensities in the ratio 25 : 16. Find the ratio of the intensities of maxima to minima, after interference of light occurs.

Ans : **Comp 2019**

As we know that

$$\text{Amplitude ratio,} \quad r = \sqrt{\frac{I_1}{I_2}}$$

$$= \sqrt{\frac{25}{16}} = \frac{5}{4}$$

$$\text{Hence,} \quad \frac{I_{\max}}{I_{\min}} = \frac{(r+1)^2}{(r-1)^2}$$

$$= \frac{\left(\frac{5}{4}+1\right)^2}{\left(\frac{5}{4}-1\right)^2} = 81:1$$

143. The refractive index of glass is 1.5. What is the speed of light in glass? (Speed of light in vacuum is $3.0 \times 10^8\ \text{ms}^{-1}$).

Ans : **SQP 2011, 2003**

$$\mu = \frac{c}{v}$$

$$\text{Here,} \quad c = 3.0 \times 10^8\ \text{m/s}$$

$$\mu = 1.5$$

$$\text{or} \quad v = \frac{c}{\mu} = \frac{3 \times 10^8}{1.5} = 2 \times 10^8\ \text{ms}^{-1}$$

144. Find the ratio of intensities of two points P and Q on a screen in a Young's double slit experiment when waves from sources S_1 and S_2 have phase difference of

(1) $\frac{\pi}{3}$ and (2) $\frac{\pi}{2}$ respectively.

Ans : **SQP 2025**

$$I = 2I_0(1+\cos\phi)$$

$$I \propto (1+\cos\phi)$$

$$\text{Hence,} \quad \frac{I_P}{I_Q} = \frac{1+\cos\frac{\pi}{3}}{1+\cos\frac{\pi}{2}} = \frac{1+\frac{1}{2}}{1+0}$$

$$= \frac{3}{2} = 3:2$$

145. In Young's double experiment, the two parallel slits are made one millimetre apart and a screen is placed one metre away. What is the fringe separation when blue green of wavelength 500 nm is used?

Ans : **Main 2015**

$$d = 1\,\text{mm} = 10^{-3}\,\text{m}$$

$$\lambda = 500\,\text{nm} = 500 \times 10^{-9}\,\text{m}$$

$$\text{Fringe width,} \quad \beta = \frac{D\lambda}{d} = \frac{1 \times 500 \times 10^{-9}}{10^{-3}}\,\text{m}$$

$$= 5 \times 10^{-4}\,\text{m} = 0.5\,\text{mm}$$

146. Light of wavelength 4500 Å in vacuum enters into a glass block of refractive index 1.5. What is the wavelength of light in the glass block?

Ans : **Main 2005**

$$\text{Wavelength of light in vacuum,} \quad \lambda_v = 4500\ \text{Å}$$

$$\text{and refractive index,} \quad \mu = 1.5$$

$$\text{Refractive index,} \quad \mu = \frac{\lambda_v}{\lambda_m}$$

Thus, wavelength in the medium of refractive index (1.5).

$$\lambda_m = \frac{\lambda_v}{\mu} = \frac{4500}{1.5} = 3000\ \text{Å}$$

$$i_B = 56.30$$

147. In Young's double slit experiment, two slits are separated by 3 mm distance and illuminated by light of wavelength 480 nm. The screen is 2 m from the plane of the slits. Calculate the separation between the 8^{th} bright fringe and the 3^{rd} dark fringe observed with respect to the central bright fringe.

Ans : **Main 2017**

As know that,

$$\text{Required distance} = x_8 - x'_3$$

$$= \frac{8D\lambda}{d} - \frac{5D\lambda}{2d} = \frac{11D\lambda}{2d}$$

$$= \frac{11 \times 2 \times 480 \times 10^{-9}}{2 \times 3 \times 10^{-3}}$$

$$= 1.76 \times 10^{-3}\,\text{m}$$

$$= 1.76\,\text{mm}$$

148. Fraunhofer diffraction from a single slit of width 124×10^{-6} m is observed with the light of wavelength 6200 Å. Calculate the angular width of the central maximum.

Ans : **Main 2005**

In Fraunhofer diffraction from a single slit, central maxima is given by

$$a\sin\theta = n\lambda$$

where $a =$ width of a slit,

$\lambda =$ wavelength of the light.

$$\sin\theta = \frac{n\lambda}{a} = \frac{6200 \times 10^{-10}}{1.24 \times 10^{-6}} = 0.5$$

$$\theta = 30^\circ$$

Angular width of the central maxima,

$$2\theta = 2 \times 30^\circ = 60^\circ$$

NODIA

175. Laser light of wavelength 630 nm is incident on a pair of slits which are separated by 1.8 mm. If the screen is kept 80 cm away from the two slits, calculate

(i) fringe separation, i.e. fringe width.

(ii) distance of 10^{th} bright fringe from the centre of interference pattern.

Ans : **Main 2015**

Given, $\lambda = 630\,\text{nm} = 630 \times 10^{-9}\,\text{m}$,

$d = 1.8\,\text{mm} = 1.8 \times 10^{-3}\,\text{m}$,

$D = 80\,\text{cm} = 0.80\,\text{m}$

(i) Fringe width is given by

$$\beta = \frac{\lambda D}{d}$$

$$= \frac{630 \times 10^{-9} \times 0.80}{1.8 \times 10^{-3}} = 2.8 \times 10^{-4}\,\text{m}$$

(ii) Distance of 10th bright fringe from the centre,

$$x_n = \frac{n\lambda D}{d}$$

Here, $n = 10$

$$x_{10} = \frac{10 \times 630 \times 10^{-9} \times 0.80}{1.8 \times 10^{-3}}$$

$$= 10 \times 2.8 \times 10^{-4} = 2.8 \times 10^{-3}\,\text{m}$$

176. In Young's double slit experiment using monochromatic light of wavelength 600 nm, 5^{th} bright fringe is at a distance of 0.48 mm from the centre of the pattern. If the screen is at a distance of 80 cm from the plane of the two slits, calculate

(i) distance between the two slits.

(ii) fringe width, i.e. fringe separation.

Ans : **Main 2017**

Wavelength, $\lambda = 600\,\text{nm} = 600 \times 10^{-9}\,\text{m}$

5^{th} bright fringe observed at distance,

$$x = 0.48\,\text{mm}$$

$$= 0.48 \times 10^{-3}\,\text{m}$$

Distance between screen and slits,

$$D = 80\,\text{cm} = 80 \times 10^{-2}\,\text{m}$$

(i) Distance between two slits, nth bright fringe is observed at,

$$X_n = \frac{nD\lambda}{d}$$

$$0.48 \times 10^{-3} = \frac{5 \times 80 \times 10^{-2} \times 6000 \times 10^{-9}}{d}$$

$$d = \frac{5 \times 80 \times 10^{-2} \times 600 \times 10^{-9}}{0.48 \times 10^{-3}}$$

$$= 5 \times 10^{-3}\,\text{m}$$

(ii) Fringe width i.e. fringe separation

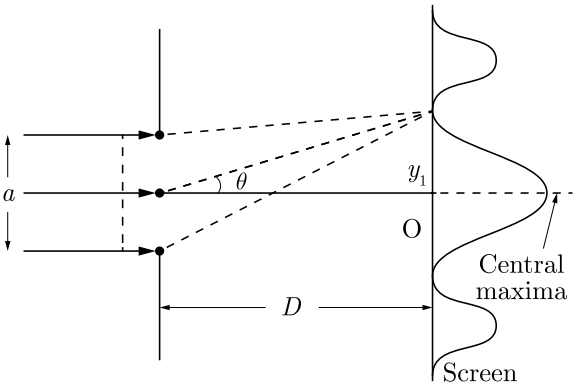
It is given by, $\beta = \frac{D\lambda}{d}$

$$= \frac{80 \times 10^{-2} \times 600 \times 10^{-9}}{5 \times 10^{-3}}$$

$$= 9.6 \times 10^{-5}\,\text{m}$$

177. A parallel beam of light of 500 nm falls on a narrow slit and the resulting diffraction pattern is observed on a screen 1 m away. It is observed that the first minimum is at a distance of 2.5 mm from the centre of the screen. Calculate the width of the slit.

Ans : **Main 2013, 2018**



Ans :

From condition of diffraction,

$$\sin\theta = n\lambda \qquad \text{(for minima)}$$

$$= \left(n + \frac{1}{2}\right)\lambda \qquad \text{(for maxima)}$$

Given $n = 1, 2, 3, ...$

and $n = 0$ for central maxima

From condition of minima.

$$a\sin\theta = \lambda(n = 1)$$

Since the value of λ is of nm, so

$$a \cdot \theta = \lambda$$

$$a \cdot \frac{y}{D} = \lambda \qquad \left[\text{angle} = \frac{\text{arc}}{\text{radius}}\right]$$

$$a = \frac{\lambda D}{y} = \frac{500 \times 10^{-9} \times 1}{2.5 \times 10^{-3}}\,\text{m}$$

$$= 2 \times 10^{-4}\,\text{m}$$

178. Two wavelengths of sodium light 590 nm and 596 nm are used, in turn, to study the diffraction taking place at a single slit of aperture 2×10^{-4} m. The distance between the slit and the screen is 1.5 m. Calculate the separation between the positions of the first maxima of the diffraction pattern obtained in the two cases.

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Now, angular width of central maxima,

$$\phi = 2\theta = \frac{2\lambda}{d}$$
$$= \frac{2 \times 650 \times 10^{-9}}{1.3 \times 10^{-4} \times 10^{-2}}$$
$$= \frac{13000}{13} \times 10^{-3} = 1\,\text{rad}$$

Thus, the angular width of the central maxima is 1 rad.

155. In Young's double slit experiment, using monochromatic light of wavelength 600 nm, the interference pattern was obtained on a screen kept 1.5 m away from the plane of the two slits. Calculate the distance between the two slits, if fringe separation/fringe width was found to be 1.0 mm.

Ans : **Main 2012**

Fringe width,

$$\beta = 1\,\text{mm} = 10^{-3}\,\text{m}$$

Wavelength, $\lambda = 600\,\text{nm}$, $D = 1.5\,\text{m}$, $d = ?$

$$\beta = \frac{D}{d}\lambda \qquad \text{[from YDSE]}$$

Distance between two slits

$$d = \frac{D\lambda}{\beta}$$
$$= \frac{(1.5)(600 \times 10^{-9})}{10^{-3}}$$
$$= 9 \times 10^{-4}\,\text{m}$$

156. In Young's double slit experiment, using light of wavelength 400 nm, interference fringes of width X are obtained. The wavelength of light is increased to 600 nm and the separation between the slits is halved. If one wants the observed fringe width on the screen to be the same in the two cases, find the ratio of the distance between the screen and the plane of the interfering sources in the two arrangements.

Ans : **SQP 2019, 2013**

Fringe width X is same in both cases.

In first case, $X = \frac{D_1\lambda_1}{d}$

In second case, $X = \frac{D_2\lambda_2}{\frac{d}{2}}$

Hence, $\frac{D_1\lambda_1}{d} = \frac{D_2\lambda_2}{\frac{d}{2}}$

or $\frac{D_1}{D_2} = 2 \cdot \frac{\lambda_2}{\lambda_1} = \frac{2 \times 600}{400}$

$$= \frac{3}{1} = 3:1$$

157. In Young's experiment, the width of the fringes obtained with light of wavelength 6000 Å is 2.0 mm. Calculate the fringe width if the entire apparatus is immersed in a liquid medium of refractive index 1.33.

Ans : **SQP 2009**

Given, $\beta = 2.0\,\text{mm}$

$\mu = 1.33$

Refractive index of liquid,

$$\mu = \frac{\text{Wavelength of light in vacuum}}{\text{Wavelength of light in liquid}}$$

or $\lambda' = \frac{\lambda}{\mu}$

Fringe width in air,

$$\beta = \frac{D\lambda}{d}$$

Fringe width in liquid,

$$\beta' = \frac{D\lambda'}{d} = \frac{D\lambda}{d\mu} = \frac{\beta}{\mu}$$
$$= \frac{2.0\,\text{mm}}{1.33}$$
$$= 1.5\,\text{mm}$$

158. In double slit experiment using light of wavelength 600 nm, the angular width of a fringe formed on a distant screen is 0.1°. What is the spacing between the two slits ?

Ans : **SQP 2016, 2009**

Wavelength of light,

$$\lambda = 600\,\text{nm}$$
$$= 600 \times 10^{-9}\,\text{m}$$

Angular width of fringe,

$$\theta = 0.1^\circ$$
$$= \frac{0.1\pi}{180}\,\text{rad}$$

Using the formulae, $\theta = \frac{\lambda}{d}$

Spacing between the slits,

$$d = \frac{\lambda}{\theta}$$
$$= \frac{600 \times 10^{-9} \times 180}{0.1 \times \pi}$$
$$d = 3.44 \times 10^{-4}\,\text{m}$$

Thus, the spacing between the two slits is 3.44×10^{-4} m

NODIA

Destructive Interference : For minimum intensity at any point $\cos\phi = -1$

or phase difference, $\phi = \pi, 3\pi, 5\pi, 7\pi, ...$

$$= (2n-1)\pi, n = 1, 2, 3, ...$$

...(13)

In this case the minimum intensity,

$$I_{\max} = a_1^2 + a_2^2 - 2a_1a_2$$

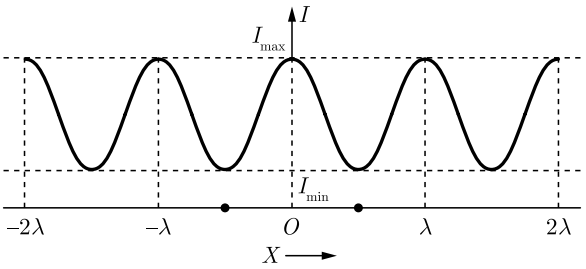
$$= (a_1 - a_2)^2 \quad ...(14)$$

$$\text{Path difference, } \Delta = \frac{\lambda}{2\pi} \times \text{Phase difference}$$

$$= \frac{\lambda}{2\pi} \times (2n-1)\pi$$

$$= (2n-1)\frac{\lambda}{2}$$

Clearly, the minimum intensity is obtained in the region of superposition at those points where waves meet in opposite phase or the phase difference between the waves is odd multiple of π or path difference between the waves is odd multiply of $\frac{\lambda}{2}$ and minimum intensity $= (a_1 - a_2)^2$ which is less than the sum of intensities of the individual waves by an amount $2a_1a_2$.



From equations (12) and (14). it is clear that the intensity $2a_1a_2$ is transferred from positions of minima to maxima. This implies that the interference is based on conservation of energy i.e., there is no wastage of energy.

Variation of intensity of light with position x is shown in figure.

NUMERICAL QUESTIONS

137. What should be the width of each slit in order to obtain 10 maxima of the double slits pattern within the central maximum of the single slit pattern ?

Ans : SQP 2015

$$\beta_0 = \frac{2\lambda D}{d} = 10\beta$$

$$d = \frac{2 \times 500 \times 10^{-9} \times 1}{10 \times 5 \times 10^{-4}} = 2 \times 10^{-4}\,\text{m}$$

138. Obtain the ratio of the interference fringe widths β_1 and β_2 obtained with monochromatic red light of $\lambda_1 = 660\,\text{nm}$ and ultraviolet light of $\lambda_2 = 330\,\text{nm}$.

Ans : Main 2003

Fringe width, $\beta = \frac{\lambda D}{d}$

According to question, by taking the ratio of two different situation.

$$\frac{\beta_1}{\beta_2} = \frac{\lambda_1 D/d}{\lambda_2 D/d} = \frac{\lambda_1}{\lambda_2} = \frac{660}{330} = 2:1$$

139. In Young's double slit experiment, two slits are 1 mm apart and the screen is placed 1 m away from the slits. Calculate the fringe width when light of wavelength 500 nm is used.

Ans : SQP 2016, 2009

Fringe width is given by

$$\beta = \frac{\lambda D}{d}$$

$$= \frac{500 \times 10^{-9} \times 1}{10^{-3}} = 0.5\,\text{mm}$$

$$= 0.5 \times 10^{-3}\,\text{m}$$

$$= 5 \times 10^{-4}\,\text{m}$$

140. What is the ratio of slit widths, when amplitude of light wave from them have a ratio $\frac{\sqrt{2}}{1}$?

Ans : Main 2017

If W_1 and W_2 are the widths of slits and a_1 and a_2 respectively, the amplitude of light waves then, we have

$$\frac{W_1}{W_2} = \frac{a_1^2}{a_2^2} = \left(\frac{a_1}{a_2}\right)^2$$

$$= \left(\frac{\sqrt{2}}{1}\right)^2 = \frac{2}{1}$$

141. Determine the angular separation between the central maxima and the first order maxima of the diffraction pattern due to a single slit of width 0.25 mm when light of wavelength 5890 Å is incident on its normally.

Ans : Main 2006, 2000

The angular separation between the central maxima,

$$d\sin\theta = n\lambda$$

Where, symbols have their usual meaning.

For first order maxima, $n = 1$

$$\sin\theta = \frac{5890 \times 10^{-10}}{0.25 \times 10^{-3}}$$

$$\theta \approx \sin\theta = 0.0023\,\text{rad} \quad [\text{For small } \theta]$$

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Separation of fringes,

$$x = \frac{n\lambda D}{d}$$

$$d = \frac{n\lambda D}{x}$$

$$= \frac{10 \times (5100 \times 10^{-10}) \times 2}{2 \times 10^{-3}}$$

$$= 5.1 \times 10^{-4}\text{m}$$

164. Width of two slits in Young's experiment are in ratio of 1 : 4. What is the ratio of intensities of light wave from them?

Ans : **Main 2012**

The width of a slit is directly proportional to the amplitude of light (i.e. electric vector).

If W_1 and W_2 are the width of slits and a_1 and a_2 are their respective amplitude of light waves, then

$$W_1 \propto a_1^2$$

and $$W_2 \propto a_2^2$$

Hence, $$\frac{W_1}{W_2} = \frac{a_1^2}{a_2^2}$$

$$\frac{1}{4} = \frac{a_1^2}{a_2^2}$$

$$\frac{a_1}{a_2} = \frac{1}{2} \quad ...(1)$$

If I_{max} and I_{min} are maximum and minimum values of intensities of light, then

$$\frac{I_{max}}{I_{min}} = \frac{(a_1 + a_2)^2}{(a_1 - a_2)^2} = \frac{\left(\frac{a_1}{a_2} + 1\right)^2}{\left(\frac{a_1}{a_2} - 1\right)^2}$$

$$= \frac{\left(\frac{1}{2} + 1\right)^2}{\left(\frac{1}{2} - 1\right)^2} = \frac{9}{1} = 9$$

165. In Young's double slit experiment, the distance of the 4th bright fringe from the centre of the interference pattern is 1.5 mm. The distance between the slits and the screen is 1.5 m and the wavelength of light used is 500 nm. Calculate the distance between the two slits.

Ans : **SQP 2011, 2009**

Given,Distance between two slits is d.

Distance from the slits to the screen is 'D'.

Distance from the central bright fringe to the nth bright fringe is y_n .

The distance from the central bright fringe to the 4th bright fringe $= y_4 = 1.5\,\text{mm} = 0.0015\,\text{m}$.

The distance between the slits can be

$$d = \frac{n \times \lambda \times D}{y_n}$$

$$= \frac{4 \times 500 \times 10^{-7} \times 15}{0.0015}$$

$$= \frac{4 \times 500 \times 10^{-7} \times 1.5 \times 10^4}{15}$$

$$= \frac{4 \times 50 \times 10^{-3} \times 15}{15}$$

$$= 200 \times 10^{-3} = 2 \times 10^{-1}$$

$$d = 0.2\,\text{m}$$

166. A parallel beam of light of wavelength 500 nm falls on a narrow slit and the resulting diffracting pattern is observed on a screen 1 m away. It is observed that the first minimum is at a distance of 2.5 mm from the centre of the screen. Calculate the width of the slit.

Ans : **Main 2013**

The distance of the nth minimum from the centre of the screen is

$$x_n = \frac{nD\lambda}{d} \quad ...(1)$$

where, D = distance of slit from screen

λ = wavelength of the light

d = width of the slit for first minimum,

$n = 1$

$x_n = 2.5\,\text{mm} = 2.5 \times 10^{-3}\,\text{m}$

$D = 1\,\text{m}$

$\lambda = 500\,\text{nm} = 500 \times 10^{-9}\,\text{m}$

Putting this values in equations (1), we get

$$2.5 \times 10^{-3} = \frac{1(1)(500 \times 10^{-9})}{d}$$

$$d = 2 \times 10^{-4}\,\text{m} = 0.2\,\text{mm}$$

167. Two sources of intensity I and $4I$ are used in an interference experiment. Find the intensity at points where the waves from two sources superimpose with a phase difference (1) zero (2) $\frac{\pi}{2}$ and (3) π.

Ans : **SQP 2014**

The resultant intensity at a point where phase difference is ϕ is,

$$I_R = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$$

As, $$I_1 = I$$

and $$I_2 = 4I$$

Therefore, $$I_R = I + 4I + 2\sqrt{I \cdot 4I}\cos\phi$$

$$= 5I + 4I\cos\phi$$

1. When $\phi = 0$, then

$$I_R = 5I + 4I\cos 0 = 9I$$

NODIA

2. When $\phi = \frac{\pi}{2}$, then

$$I_R = 5I + 4I\cos\frac{\pi}{2} = 5I$$

3. When $\phi = \pi$, then

$$I_R = 5I + 4I\cos\pi = 5I - 4I = I$$

168. Yellow light of wavelength 6000 Å produces fringes of width 0.8 mm in Young's double slit experiment. What will be the fringe width if the light source is replaced by another monochromatic source of wavelength 7500 Å and the separation between the slits is doubled?

Ans : **SQP 2017**

Given, $\lambda_1 = 6000\,\text{Å}$

$\beta_1 = 0.8\,\text{mm}$

$\lambda_2 = 7500\,\text{Å}$

Fringe width in first case,

$$\beta_1 = \frac{D\lambda_1}{d}$$

Fringe width in second case,

$$\beta_2 = \frac{D\lambda_2}{2d}$$

Hence, $\frac{\beta_2}{\beta_1} = \frac{\frac{D\lambda_2}{2d}}{\frac{D\lambda_1}{d}} = \frac{1}{2}\cdot\frac{\lambda_2}{\lambda_1}$

$$\beta_2 = \frac{1}{2}\cdot\frac{\lambda_2}{\lambda_1}\cdot\beta_1$$

$$= \frac{1}{2}\times\frac{7500\,\text{Å}}{6000\,\text{Å}}\times 0.8\,\text{mm}$$

$$= 0.5\,\text{mm}$$

169. The fringe width in a Young's double slit interference pattern is $2.4\times10^{-4}\,\text{m}$, when red light of wavelength 6400 Å is used. By how much will it change, if blue light of wavelength 4000 Å is used.

Ans : **Comp 2012**

Given, $\beta_1 = 2.4\times10^{-4}\,\text{m}$

$\lambda_1 = 6400\,\text{Å}$

$\lambda_2 = 4000\,\text{Å}$

As know that

$$\beta = \frac{D\lambda}{d}$$

$$\frac{\beta_2}{\beta_1} = \frac{\lambda_2}{\lambda_1} = \frac{4000}{6400} = \frac{5}{8}$$

$$\beta_2 = \frac{5}{8}\times\beta_1$$

$$= \frac{5}{8}\times 2.4\times10^{-4}$$

$$= 1.5\times10^{-4}\,\text{m}$$

Decrease in fringe width

$$= \beta_1 - \beta_2$$

$$= (2.4 - 1.5)\times10^{-4}$$

$$= 0.9\times10^{-4}\,\text{m}$$

170. In Young's double slit experiment using monochromatic light L_1 of wavelength 700 nm, 10^{th} bright fringe was obtained at a certain point P on a screen. Which bright fringe will be obtained at the same point P, if monochromatic light of wavelength 500 nm is used in place of L_1. (No other alterations were made in the experimental set up.)

Ans : **Main 2025**

According to the question, for the same arrangement of YDSE, the ratio of d/D remains constant.

$$y_n = n\frac{D}{d}\lambda$$

Given, $\lambda_1 = 700\,\text{nm}$,

$n_1 = 10\text{th bright fringe}$,

$\lambda_2 = 500\,\text{nm}$, $n_2 = ?$

$$y = n\frac{D\lambda}{d}$$

For the same point, x is constant and for same arrangement, then $\frac{d}{D}$ is constant.

$$n_1\lambda_1 = n_2\lambda_2$$

$$10\times700 = n_2\times500$$

$$n_2 = \frac{10\times700}{500} = 14$$

171. What is the value of maximum amplitude produced due to interference of two waves is given by $y_1 = 4\sin\omega t$ and $y_2 = 3\cos\omega t$?

Ans : **Comp 2018, 2013**

Given,

$$y_1 = 4\sin\omega t \quad ...(1)$$

$$y_2 = 3\cos\omega t$$

$$y_2 = 3\sin\left(\tfrac{\pi}{2} + \omega t\right) \quad ...(2)$$

After compare Eq. (1) and (2) with a standard equation, we get

$$A_1 = 4$$

$$A_2 = 3$$

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Initial phase difference,

$$\phi = \frac{\pi}{2}$$

Resultant amplitude,

$$A = \sqrt{A_1^2 + A_2^2 + 2A_1A_2\cos\phi}$$

$$\cos\phi = 1$$

For maximum amplitude,

Hence, $\phi = 0^\circ$

$$A = \sqrt{(A_1 + A_2)^2}$$

So, $A_{max} = A_1 + A_2$

$$= 3 + 4 = 7$$

172. The distance between the first and the sixth bright fringes formed in Young's double slit experiment (measured by a spectrometer) is found to be 12.5 mm.The separation between the slits 0.12 mm and the distance of the screen from the slits is 60 cm.

Calculate

(i) the fringe width.

(ii) the wavelength of the light used (in nm).

Ans : **Main 2007, 2000**

(i) $y_n = n\frac{D\lambda}{d}$

where, $n = 0, 1, 2,....$

Here, $y_6 - y_1 = 12.5\,\text{mm}$

$$y_6 - y_1 = \frac{D\lambda}{d}(6-1) = 5\beta \left[\beta = \frac{D\lambda}{d}\right]$$

So, fringe width $\beta = \frac{12.5}{5} = 2.5\,\text{mm}$

(ii) Since, $\beta = \frac{D\lambda}{d}$

Given, $D = 60\,\text{cm} = 0.6\,\text{m}$,

$$d = 0.12\,\text{mm} = 0.12 \times 10^{-3}\,\text{m}$$

$$2.5 \times 10^{-3} = \frac{0.6 \times \lambda}{0.12 \times 10^{-3}}$$

$$\lambda = 5 \times 10^{-7}\,\text{m} = 5000\,\text{Å}$$

173. Two beams of light having intensities I and $4I$ interfere to produce a fringe pattern on a screen. The phase difference between the beams is $\frac{\pi}{2}$ at point A and π at point B. What is the difference between the resultant intensities at A and B?

Ans : **SQP 2010**

Given,

Intensity of first beam,

$$I_1 = I$$

And intensity of second beam,

$$I_2 = 4I$$

Phase difference between the beams at point,

$$A(\phi_A) = \frac{\pi}{2}$$

And phase difference between the beams at point,

$$B(\phi_B) = \pi$$

The resultant intensity of beams at,

$$A(I_A) = I_1 + I_2 + 2\sqrt{I_1I_2}\cos\phi_A$$

$$= I + 4I + 2\sqrt{I \times 4I}\cos\left(\frac{\pi}{2}\right)$$

$$= 5I$$

Similarly, resultant intensity of beam at,

$$B(I_B) = I_2 + I_2 + 2\sqrt{I_1I_2}\cos\phi_B$$

$$= I + 4I + 2\sqrt{I \times 4I}\cos\pi$$

$$= I$$

Therefore, difference between the resultant intensities at A and B

$$= I_A - I_B = 5I - I = 4I$$

174. In Young double slit experiment, distance between slits is 0.28 mm and distance between slits and screen is 1.4 m. Distance between central bright fringe and third bright fringe is 0.9 cm. What is the wavelength of used light?

Ans : **SQP 2017, 2012**

Given,

Distance between slits,

$$d = 0.28\,\text{mm} = 0.28 \times 10^{-3}\text{m}$$

Distance between slits and screen,

$$D = 1.4\,\text{m}$$

Distance between central bright fringe and third bright fringe,

$$x_3 = 0.9\,\text{cm} = 0.9 \times 10^{-2}\text{m}$$

And number of bright fringe,

$$n = 3$$

Distance of third bright fringe from the central fringe,

$$x_3 = \frac{n\lambda D}{d}$$

$$\lambda = \frac{x_3 \times d}{nD}$$

$$= \frac{(0.9 \times 10^{-2}) \times (0.28 \times 10^{-3})}{3 \times 1.4}$$

$$= 6 \times 10^{-7}\text{m} = 6000\dot{\text{A}}$$

Where, $\lambda =$ Wavelength of used light

NODIA

159. In Young's double slit experiment, the slits are 0.2 mm apart and the screen is 1.5 m away. It is observed that the distance between the central bright fringe and fourth dark fringe is 1.8 cm. Find the wavelength of light used.

Ans : **Main 2013**

Given, $d = 0.2\,\text{mm} = 0.2 \times 10^{-3}\,\text{m}$

$D = 1.5\,\text{m}$

$x'_4 = 1.8\,\text{cm} = 1.8 \times 10^{-3}\,\text{m}$

The distance of n^{th} dark fringe from the central bright fringe is given by,

$$x'_n = (2n-1)\frac{D\lambda}{2d'}$$

Hence, $x'_4 = \frac{7}{2} \cdot \frac{D\lambda}{d}$

or $\lambda = \frac{2dx'_4}{7D}$

$$= \frac{2 \times 0.2 \times 10^{-3} \times 1.8 \times 10^{-2}}{7 \times 1.5}$$

$$= 6.86 \times 10^{-7}\,\text{m}$$

160. Light of wavelength 600 nm, falls normally on a slit of width 1.2 μm producing Fraunhoffer diffraction pattern on a screen. Calculate the angular position of the first minima and the angular width of the central

Ans : **Main 2002**

Wavelength, $\lambda = 600\,\text{nm} = 600 \times 10^{-9}\,\text{m}$

$d = 1.2\,\mu\text{m} = 1.2 \times 10^{-6}\,\text{m}$

Angular position of the first minima,

$$\sin\theta = \frac{\lambda}{d}$$

$$\sin\theta = \frac{600 \times 10^{-9}}{1.2 \times 10^{-6}}$$

$$\sin\theta = 0.5 = \frac{1}{2}$$

$$\sin\theta = \sin 30^\circ$$

$$\theta = 30^\circ$$

Angular width of the central maxima

$$= \frac{2\lambda}{d} = \frac{2 \times 600 \times 10^{-9}\,\text{m}}{1.2 \times 10^{-6}} = 1\,\text{rad}$$

161. In a double slit experiment using light of wavelength 600 nm, the angular width of the fringe formed on a distant screen is 0.1°. Find the spacing between the two slits.

Ans : **Comp 2019**

Angular width (θ) of the fringe in double slit experiment is given by

$$\theta = \frac{\lambda}{d}$$

Where, d = spacing between the slits

Wavelength of light,

$$\lambda = 600\,\text{nm}$$

Angular width of fringe,

$$\theta = 0.1^\circ = \frac{\pi}{1800}$$

$$= 0.0018\,\text{rad}$$

$$d = \frac{\lambda}{\theta} = \frac{600 \times 10^{-9}}{18 \times 10^{-4}}$$

$$= 0.33 \times 10^{-3}\,\text{m}$$

162. If the ratio of intensities of two waves causing interference be 9 : 4, What is the ratio of maximum and minimum intensities ?

Ans : **Main 2015**

Given,

Intensity of first wave,

$$I_1 = 9I$$

and intensity of second wave,

$$I_2 = 4I$$

Intensity of a wave,

$$I = 2\pi^2 v^2 a^2 \;\; \rho \;\; v \propto a^2$$

$$a \propto \sqrt{I}$$

Therefore, $\frac{a_1}{a_2} = \sqrt{\frac{I_1}{I_2}} = \sqrt{\frac{9I}{4I}} = \frac{3}{2}$

We also know that ratio of maximum to minimum intensities,

$$\left(\frac{I_{\max}}{I_{\max}}\right) = \frac{(a_1 + a_2)^2}{(a_1 - a_2)^2}$$

$$= \frac{(3+2)^2}{(3-2)^2} = \frac{25}{1}$$

$$I_{\max} : I_{\min} = 25 : 1$$

163. Green light of wavelength 5100 Å from a narrow slit is incident on a double slit. If the overall separation of 10 fringes on a screen 200 cm away is 2 cm, What is the distance between the slits?

Ans : **Comp 2014**

Wave length of green light,

$$\lambda = 5100\,\text{Å} = 5100 \times 10^{-10}\text{m}$$

Number of fringe, $n = 10$

Distance between slits and screen,

$$D = 200\,\text{cm} = 2\,\text{m}$$

and separation of fringes,

$$x = 2\,\text{cm} = 2 \times 10^{-3}\,\text{m}$$

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Ans : **SQP 2013**

For maxima other than central maxima.

$$a \cdot \theta = \left(n + \frac{1}{2}\right)\lambda$$

and $$\theta = \frac{y}{D}$$

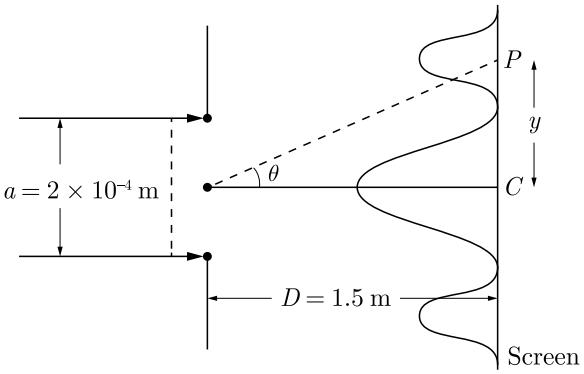
$$a \cdot \frac{y}{D} = \left(n + \frac{1}{2}\right)\lambda$$

For light of wavelength $\lambda_1 = 590\text{ nm}$

$$2 \times 10^{-14} \times \frac{y_1}{1.5} = \left(1 + \frac{1}{2}\right) \times 590 \times 10^{-9}$$

$$y_1 = \frac{3}{2} \times \frac{590 \times 10^{-9} \times 1.5}{2 \times 10^{-4}}$$

$$= 6.64\text{ mm}$$



For light of wavelength $\lambda_2 = 596\text{ nm}$

$$2 \times 10^{-4} \times \frac{y_2}{1.5} = \left(1 + \frac{1}{2}\right) \times 596 \times 10^{-9}$$

$$y_2 = \frac{3}{2} \times \frac{596 \times 10^{-9} \times 1.5}{2 \times 10^{-4}}$$

$$= 6.705\text{ mm}$$

Separation between two positions of first maxima

$$\Delta y = y_2 - y_1$$

$$= 6.705 - 6.64 = 0.065\text{ mm}$$

179. Monochromatic light of wavelength 620 nm is incident on a part of slits which are separated by 1.5 mm. If the screen is kept 60 cm away from the plane of the two slits.

Calculate

(i) fringe separation i.e. fringe width and

(ii) distance of the 10th bright fringe from centre of the interference pattern.

Ans : **Main 2022 Sem-II**

Wavelength of light,

$$\lambda = 620\text{ mm}$$

$$= 620 \times 10^{-9}\text{ m}$$

Distance between slits,

$$d = 1.5\text{ mm}$$

$$= 1.5 \times 10^{-3}\text{ m}$$

Distance between slits and screen,

$$D = 60\text{ cm}$$

$$= 60 \times 10^{-2}\text{ m}$$

(i) Fringe separation in the young double slit experiment is given by

$$\beta = \frac{D\lambda}{d}$$

$$= \frac{60 \times 10^{-2} \times 620 \times 10^{-9}}{1.5 \times 10^{-3}}$$

$$= 24800 \times 10^{-8}\text{ m}$$

$$= 0.248\text{ mm}$$

(ii) Distance of 10th bright fringe is given by

$$y_n = \frac{nD\lambda}{d} = n\beta$$

$$y_{10} = 10 \times 0.248$$

$$= 2.48\text{ mm}$$

180. In Young's double slit experiment, the screen is kept at a distance of 1.2 m from the plane of the slits. The two slits are separated by 5 mm and illuminated with monochromatic light having wavelength 600 nm.

Calculate

(i) fringe width, i.e. fringe separation of the interference pattern.

(ii) distance of 10th bright fringe from the centre of the pattern.

Ans : **SQP 2020**

Wavelength of light,

$$\lambda = 600\text{ nm}$$

$$= 600 \times 10^{-9}\text{ m}$$

$D =$ distance between slits and screen $= 1.2\text{ m}$

and $d =$ distance between two slits

$$= 5\text{ mm} = 5 \times 10^{-3}\text{ m}$$

(i) According to YDSE,

Fringe width, $\beta = \frac{D\lambda}{d}$

$$= \frac{1.2 \times 600 \times 10^{-9}}{5 \times 10^{-3}}$$

$$= 1.44 \times 10^{-4} = 0.144\text{ mm}$$

(ii) Position of 10th bright fringe,

$$y_n = n\frac{D\lambda}{d} = n\beta$$

$$y_{10} = 10 \times 0.144 = 1.44\text{ mm}$$

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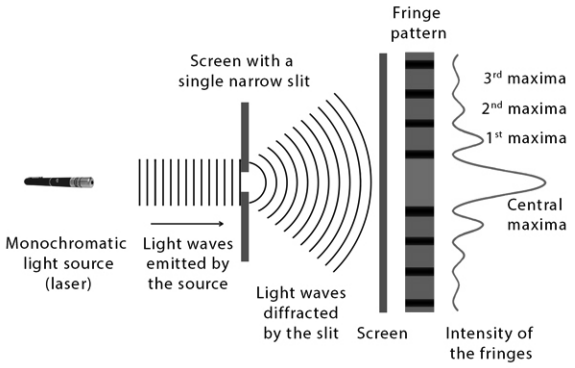


(a) What is the effect of wavelength of light on the fringe pattern?

(b) Give the necessary condition for the diffraction?

(c) Why is diffraction pattern not visible by using X-rays is such case ?

Ans :

(a) Increasing the wavelength of the light increases the spacing between different fringes since the spacing between different fringes is wavelength dependent.

(b) The size of the aperture/obstacle should be comparable to the wavelength of the light.

(c) As the wavelength of X-rays is much smaller than that of yellow high, so the diffraction pattern is not seen when the yellow light is replaced by X-rays in such condition.

187. A child is observing a thin film such as a layer of oil on water show beautiful colours when illuminated by white light. He feels happy and surprised to see this. His teacher explains him the reason behind it. The child then gives an example of spreading of kerosene oil on water to prevent malaria and dengue.

(a) Name the phenomenon involved ?

(b) What do you mean by interference?

(c) Write any four the necessary conditions for interference of light.

Ans :

(a) The phenomenon involved in a thin film is interference. Different colours of light interfere at different points in space and hence child is able to see different colours.

(b) Interference is defined as the phenomenon of superimposition of two or more waves of same frequency emitted by coherent sources such that the resultant wave is equal to the sum of the amplitude of the individual waves. Depending on whether the interference is constructive or destructive, the amplitude of the resultant wave can either be larger or smaller than the individual waves.

(c) The conditions for the interference of light are as under.

(i) Light source should be monochromatic.

(ii) Both the waves should be of same frequency.

(iii) Both the waves should be travel in the same direction.

(iv) The amplitude of both the waves should be nearly same or equal.

(v) Both the sources(slits) should be very thin.

188. In 1678, Huygens proposed the wave theory of light. According to Huygens, light travels in the form of waves. These waves after emerging from the light-source travel in all directions with the velocity of light. Since, waves require a medium to travel, Huygens imagined an all-pervading medium called 'Luminferous Ether'. It was assumed that this hypothetical medium is weightless and can penetrate through matter. It has all properties necessary for the propagation of light-waves. For example, light travels with a very high speed ($3 \times 10^8\ \text{ms}^{-1}$). Hence, it was assumed that the density of ether is very small and the elasticity is very large

(Wave speed $= \sqrt{(\text{Electricity/density})}$. Light waves travel in such a hypothetical medium.

(i) Why does light appear to travel in straight lines in spite of its wave nature?

(ii) Is Huygen's theory, light waves are longitudinal and do not require a material medium for their propagation?

(iii) Which property of light conclusively support wave nature of light?

(iv) What is the fault of Huygen's wave theory?

(v) State any one postulate of Huygen's wave theory?

NODIA

Let the new fringe with the β'.

We can write, $\beta' = \frac{D'}{d}\lambda$ ...(2)

From Eqs. (1) and (2), we get

$$\beta - \beta' = \Delta\beta = \frac{\lambda}{d}[D - D']$$

$$= \frac{\lambda}{d}\Delta D$$

Given, $\Delta\beta = 3 \times 10^{-5}\,\text{m}$,

$\Delta D = 5 \times 10^{-2}\,\text{m}$

$d = 10^{-3}\,\text{m}$, $\lambda = ?$

λ = wavelength of light

Now, $3 \times 10^{-5}\,\text{m} = \frac{\lambda}{10^{-3}\,\text{m}} \times 5 \times 10^{-2}\,\text{m}$

$$\lambda = \frac{3 \times 10^{-5} \times 10^{-3}}{5 \times 10^{-2}}$$

$$= 0.6 \times 10^{-6}$$

$$= 6 \times 10^{-7}\,\text{m}$$

$$= 6000\,\text{Å}$$

CASE BASED QUESTIONS

184. Sonu and Kabir were going to their friend's house by walk. It was a sunny day in the afternoon. It was very hot. Sonu was finding it very difficult to see around him. He had to strain his eyes to see. Suddenly, Kabir took his cooling glasses from his pocket and asked him to wear them and later, Sonu slowly managed to see, Kabir advised Sonu on the necessity of wearing Sun glasses during summer season.

(i) Why do we people wear sunglasses during hot days?

(ii) Name the phenomenon based on which cooling glasses reduce the glare.

(iii) What is the resultant intensity of light if both polariser and analyser are rotated thorough same angle ?

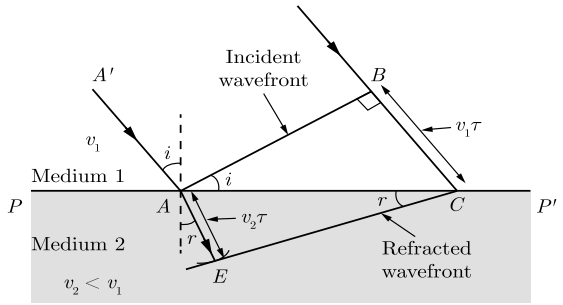
Ans :

(i) On a bright, sunny day, sunlight can bounce off from anything at any time. Wearing sunglasses with UV protection can protect you from extreme brightness from driving during a sunny day. This allows you to focus on the road better as you get to your destination.

(ii) Polarisation

(iii) No change in intensity of light.

185. Waves change direction when they pass from one medium to another. This phenomenon is called refraction. Refraction can occur in different types of mediums like sound, water, etc. Refraction is the bending of light waves. The amount of refraction depends on the change in the speed of light and the angle at which the waves are bending.
Snell's law shows the relationship between angles of incidence and refraction, and the refractive index of each medium. The refractive index refers to the extent to which a medium can increase or decrease the speed of light.



1. What is the angle made by the ray of light on the wavefront?
2. Which parameter remains unchanged while a ray of light propagates from one medium to another?
3. Write the correct expression for Snell's law for given diagram?

Ans :

1. 90°
2. Frequency.
3. $n_1 \sin i = n_2 \sin r$

186. Sunil is using yellow light in a single slit diffraction experiment with slit width of 0.6 mm. When his friend replaced yellow light by X-rays then diffraction pattern is not visible. They became frightened and asked the teacher about such thing. The teacher replaces X-rays by yellow light and diffraction pattern appears again. Then teacher explained all the facts about diffraction properly

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Ans : **Main 2018**

According to de-Broglie, wavelength of moving particle is given by

$$\lambda = \frac{h}{mv} = \frac{h}{p} \qquad [mv = p]$$

$$p = \frac{h}{\lambda} \text{ (momentum of particle)}$$

Thus (b) is correct option.

5. The energy associated with light of which of the following colours is minimum?

(a) Violet (b) Red

(c) Green (d) Yellow

Ans : **Main 2019**

The energy of light,

$$E = \frac{hc}{\lambda} \text{ or } E \propto \frac{1}{\lambda}$$

Since, red colour has maximum wavelength. So, the energy of light for red colour will be minimum.

$$E = hv \Rightarrow E \propto v$$

Thus (b) is correct option.

6. In photoelectric effect, the graph of stopping potential V_s versus frequency f of the incident radiation is a straight line. Then, slope m of this line, Planck's constant h and elementary charge e are related as follows

(a) $h = em$ (b) $m = eh$

(c) $e = mh$ (d) $e = m\pi h$

Ans : **Main 2022 Sem-II**

In V_S versus f graph, the slope is given by

$$m = \frac{h}{e} \Rightarrow h = em$$

Thus (a) is correct option.

7. The energy of a photon of wavelength λ is

(a) $hc\lambda$ (b) $\frac{hc}{\lambda}$

(c) $\frac{h\lambda}{c}$ (d) $\frac{\lambda}{hc}$

Ans : **Main 2016**

The energy of photon is given by,

$$E = h\nu$$

where, ν = frequency of photon

Hence, $$\nu = \frac{c}{\lambda}$$

$$E = \frac{hc}{\lambda}$$

Thus (b) is correct option.

8. Einstein's photoelectric equation is,

(a) $E_{max} = h\lambda - \phi_0$ (b) $E_{max} = \frac{hc}{\lambda} - \phi_0$

(c) $E_{max} = hv + \phi_0$ (d) $E_{max} = \frac{hc}{\lambda} + \phi_0$

Ans : **Main 2018, 2015**

Einstein's photoelectric equation is given by

$$E_{max} = hv - \phi_0$$

or $$E_{max} = \frac{hc}{\lambda} - \phi_0 \qquad \left[v = \frac{c}{\lambda}\right]$$

where, ϕ_0 = work function.

Thus (b) is correct option.

9. The value of 1 MeV is

(a) 1.6×10^{-19} J (b) 1.6×10^{-16} J

(c) 1.6×10^{-13} J (d) 1.6×10^{-11} J

Ans : **SQP 2015**

We know that,

$$1\,\text{eV} = 1.6 \times 10^{-19}\,\text{J}$$

Therefore,

$$\text{Value of } 1\,\text{MeV} = 10^6\,\text{eV}$$
$$= 10^6 \times (1.6 \times 10^{-19})$$
$$= 1.6 \times 10^{-13}\,\text{J}$$

Thus (c) is correct option.

10. Which one of following is charge less?

(a) Alpha particle (b) Beta particle

(c) Photon particle (d) Proton

Ans : **Comp 2024**

A photon is a tiny packet of light energy and carries no electric charge, so it is electrically neutral. An alpha particle has positive charge, a beta particle usually has negative charge, and a proton also carries positive charge. Therefore, only the photon is charge-less.

Thus (c) is correct option.

11. If the velocity of an electron increases, then its de-Broglie wavelength will

(a) increase (b) decrease

(c) remain the same (d) first a then c

Ans : **SQP 2004**

De-Broglie wavelength of electronic,

$$\lambda = \frac{h}{mv} \propto \frac{1}{v}$$

(where, v = Velocity of electron)

Therefore, if velocity increases, the de-Broglie's wavelength will decreased and vice-versa.

Thus (b) is correct option.

NODIA

Ans :

(i) Light appears to travel in straight lines in spite of its wave nature because of very small wavelength of light.

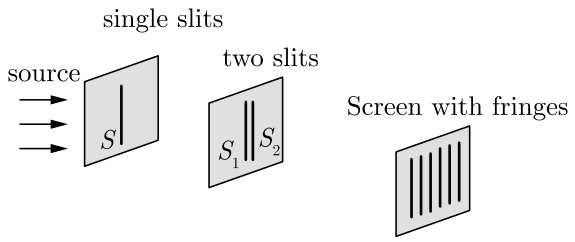
(ii) In Huygen's theory, light waves are longitudinal and require a material medium for their propagation. That's why Huygen's assumed the existence of all-pervading hypothetical medium, called ether.

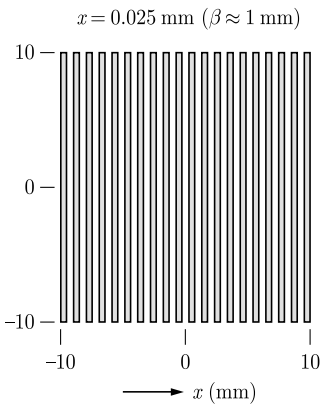
(iii) Interference of light is the property which supports the wave nature of light.

(iv) Huygen's principle failed to explain the photoelectric effect.

(v) The new position of the wavefront at any instant is envelope of the secondary wavelets at that instant.

189. Young's double-slit experiment uses two coherent sources of light placed at a small distance apart. Usually, only a few orders of magnitude greater than the wavelength of light are used. Young's double-slit experiment helped in understanding the wave theory of light, which is explained with the help of a diagram.





1. What is the path difference between the two light waves coming from coherent sources which produces 3rd maxima?
2. What is the correct expression for fringe width (β)?
3. What is the phase difference between two interfering waves producing 1st dark fringe?
4. The ratio of the widths of two slits in Young's double slit experiment is 4:1. Evaluate the ratio of intensities of maxima and minima in the interference pattern?
5. In a Young's double slit experiment, the separation between the slits is 0.1 mm, the wavelength of light used is 600 mm and the interference pattern is observed on a screen 1m away. Find the separation between bright fringes?

Ans :

1. 3λ
2. $\frac{\lambda D}{d}$
3. π
4. 9:1
5. 6.0 m.

190. When two or more, waves travel simultaneously in a medium, the resultant displacement at each point of the medium at any instant is equal to the vector sum of the displacements produced by the two waves separately. This principle is called 'principle of superposition'. It holds for all types of waves, except for the waves of very large amplitude, such as laser waves.

The principle of superposition means that if a number of waves are travelling in a medium, then each one travels independently as if the other waves were not present at all; the shape and other characteristics of any wave are not changed due to the presence of other waves. This is seen in practice. When we listen to an orchestra, we receive a complex sound due to the superposition of sound waves of different characteristics produced by different musical instruments. Still we can recognize separately the sounds of different instruments. Similarly, our radio antenna is open to the waves of different frequencies transmitted simultaneously by different radio stations. But when we tune the radio to a particular station, we receive the programmes of that station only as if the other stations were silent. Thus, the principle of superposition holds not only for mechanical waves but also for electromagnetic waves. Obviously, it holds for light waves also.

(i) What do you mean by the term principle of superposition?

(ii) Which wave is not holds by the principle of superposition?

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181. In a Young's double slit experiment, the intensity of light at a point on the screen where the path difference is λ is k units. Find the intensity at a point where the path difference is
(1) $\frac{\lambda}{4}$, (2) $\frac{\lambda}{3}$ and (3) $\frac{\lambda}{2}$.

Ans : Main 2018

Intensity at any point on the screen,

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$$

Let I_0 be the intensity of either source.

Then, $I_1 = I_2 = I_0$

and $I = 2I_0(1+\cos\phi)$

$$= 4I_0\cos^2\frac{\phi}{2}$$

When, $p = \lambda$

$\phi = 2\pi$

Hence, $I = 4I_0\cos^2\frac{\phi}{2}$

$= 4I_0\cos^2\pi = 4I_0 = k$

1. When $p = \frac{\lambda}{4}$ and $\phi = \frac{\pi}{2}$, then

$$I = 4I_0\cos^2\frac{\pi}{4}$$

$$= 4I_0 \times \frac{1}{2} = 2I_0 = \frac{k}{2}$$

2. When $p = \frac{\lambda}{3}$ and $\phi = \frac{2\pi}{3}$, then

$$I = 4I_0\cos^2\frac{\pi}{3}$$

$$= 4I_0 \times \frac{1}{4} = I_0 = \frac{k}{4}$$

3. When $p = \frac{\lambda}{2}$ and $\phi = \pi$, then

$$I = 4I_0\cos^2\frac{\pi}{2} = 0$$

182. Two wavelengths of sodium light 590 nm and 596 nm are used, in turn, to study the diffraction taking place at a single slit of aperture 2×10^{-4} m. The distance between the slit and the screen is 1.5 m. Calculate the separation between the positions of the first maxima of the diffraction pattern obtained in the two cases.

Ans : SQP 2020

For maxima other than central maxima.

$$a \cdot \theta = \left(n + \frac{1}{2}\right)\lambda$$

and $\theta = \frac{y}{D}$

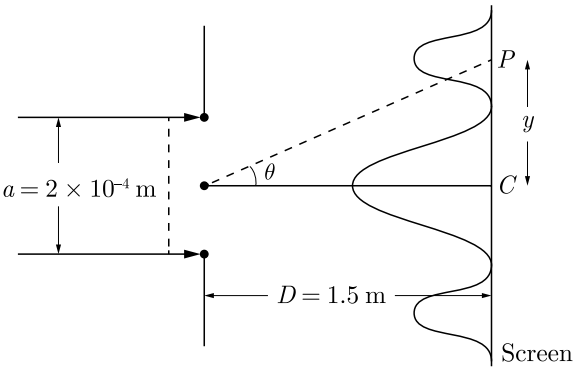
Hence, $a \cdot \frac{y}{D} = \left(n + \frac{1}{2}\right)\lambda$

For light of wavelength $\lambda_1 = 590$ nm

$$2 \times 10^{-14} \times \frac{y_1}{1.5} = \left(1 + \frac{1}{2}\right) \times 590 \times 10^{-9}$$

$$y_1 = \frac{3}{2} \times \frac{590 \times 10^{-9} \times 1.5}{2 \times 10^{-4}}$$

$$= 6.64 \text{ mm}$$



For light of wavelength $\lambda_2 = 596$ nm

$$2 \times 10^{-4} \times \frac{y_2}{1.5} = \left(1 + \frac{1}{2}\right) \times 596 \times 10^{-9}$$

$$y_2 = \frac{3}{2} \times \frac{596 \times 10^{-9} \times 1.5}{2 \times 10^{-4}}$$

$$= 6.705 \text{ mm}$$

Separation between two positions of first maxima

$$\Delta y = y_2 - y_1$$

$$= 6.705 - 6.64 = 0.065 \text{ mm}$$

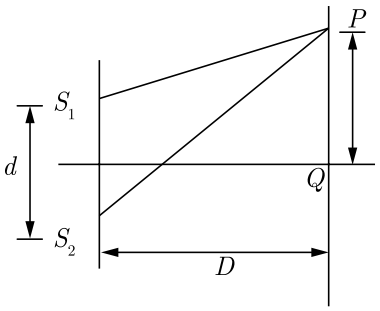
183. In Young's double slit experiment, using monochromatic light, the fringes are obtained on a screen placed at some distance from the slits. If the screen is moved by 5×10^{-2} m towards the slits, the change in the fringe width is 3×10^{-5} m. If the distance between the two slits is 10^{-3} m. Calculate the wavelength of the light used.

Ans : Main 2014, 2005, 2004

In YDSE, the fringe width depends upon the distance of the screen (D) and slit width (d).

In Young's double slit experiment, the fringe width is given by

$$\beta = \frac{D}{d}\lambda \quad \text{...(i)}$$



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CHAPTER 11

Dual Nature of Radiation and Matter

SUMMARY

1. ELECTRON EMISSION

The phenomenon is the process which gives emission of electrons from the surface of a metal. The minimum energy needed by an electron to come out from a metal surface is known as work function of the metal. It is denoted by ϕ_0 or W_0 and measured in electron volt (eV).

Work function, $W = h\upsilon_0 = \dfrac{hc}{\lambda_0}$

The electron emission can be obtained from the following physical processes.

1.1 Thermionic Emission

It is the phenomenon of emission of electrons from the metal surface when heated suitably.

1.2 Photoelectric Emission

It is the phenomenon of emission of electrons from the surface of metal when light radiations of suitable frequency fall on it.

1.3 Field Emission or Cold Cathode Emission

It is the phenomenon of emission of electrons from the surface of a metal under the application of a strong electric field.

2. PHOTOELECTRIC EFFECT

It is the phenomenon of emission of electrons from the surface of metals, when light radiations of suitable frequency fall on them.

2.1 Laws of Photoelectric Emission

The laws of photoelectric effect are as follows-

1. For a given metal and frequency of incident radiation, the number of photoelectrons ejected per second is directly proportional to the intensity of the incident light.
2. For a given metal, there exists a certain minimum frequency of the incident radiation below which no emission of photoelectrons takes place. This frequency is known as threshold frequency.
3. Above the threshold frequency, the maximum kinetic energy of the emitted photo-electron is independent of the intensity of incident light but depends only upon the frequency (or wavelength) of the incident light.
4. The photoelectric emission is an instantaneous process. The time lag between the incidence of radiation and emission of photoelectrons is very small, less than 10^{-9} second.

2.2 Photoelectric Current

Photoelectric current depends on the intensity of incident light and the potential difference applied between the two electrodes.

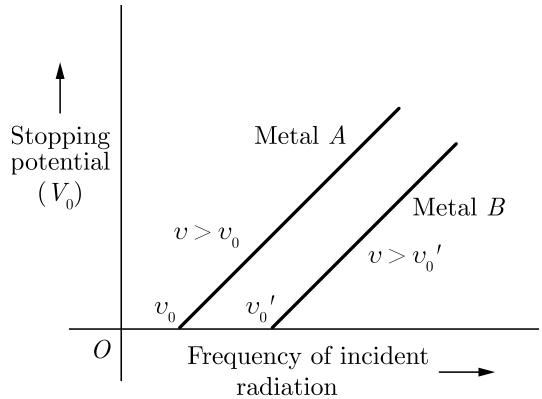
2.3 Stopping Potential

The minimum negative potential given to anode plate w.r.t. to cathode plate at which the photoelectric current becomes zero is known as stopping potential or cut off potential. It is denoted by V_0. If e is the charge on the photo-electron, then

$$K_{max} = eV_0 = \frac{1}{2}mv_{max}^2$$

Where, m is the mass of photo-electron and V_{max} is the maximum velocity of emitted photoelectrons.

1. Variation of stopping potential V_0 with frequency υ of incident radiation.



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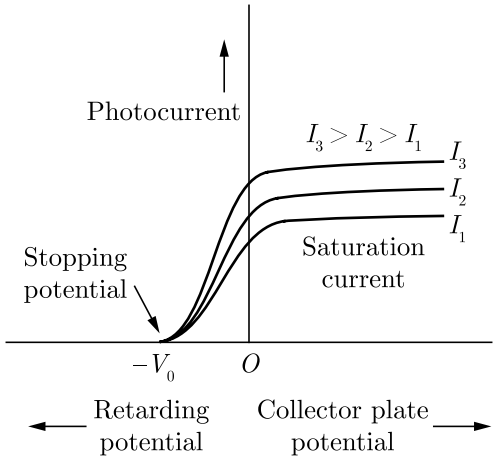
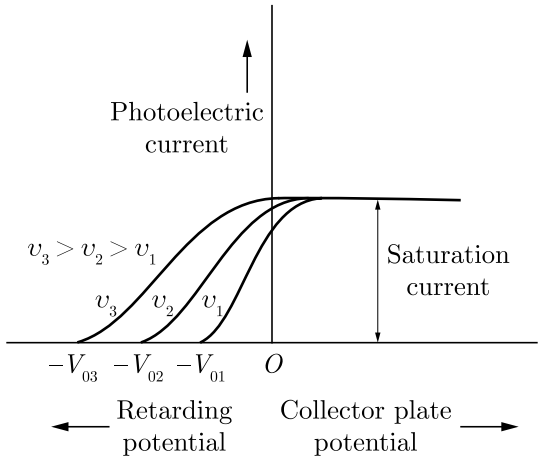
2. Variation of photo-current with collector plate potential for different intensity of incident radiation.



3. Variation of photo-current with collector plate potential for different frequencies of incident radiation.



3. EINSTEIN'S PHOTOELECTRIC EQUATION

If a light of frequency υ is incident on a photosensitive material having work function (ϕ_0) , then maximum kinetic energy of the emitted electron is given as,

$$K_{\max} = h\upsilon - \phi_0$$

For, $\upsilon > \upsilon_0$

$$eV_0 = h\upsilon - \phi_0 = h\upsilon - h\upsilon_0$$

$$eV_0 = K_{\max} = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right)$$

where, υ_0 = threshold frequency

λ_0 = threshold wavelength

λ = incident wavelength

Einstein's photoelectric equation is in accordance with the law of conservation of energy.

4. DUAL NATURE OF RADIATION

Wave theory of electromagnetic radiation explains the phenomenon of interference, diffraction and polarisation. On the other hand, photoelectric effect is supported by particle nature of light. Hence, we assume dual nature of light.

5. THE PHOTONS

These are the packets of energy (or energy particles) which are emitted by a source of radiation. The photons emitted from a source, travel through space with same speed c (equal to the speed of light).

1. Energy of a photon :
$$E = h\upsilon = \frac{hc}{\lambda}$$
where,
υ = frequency, λ = wavelength
h = Plank's constant,
c = speed of the light
2. Momentum of photon is,
$$p = \frac{E}{c} = \frac{h\upsilon}{c}$$
3. The rest mass of photon is zero.
4. The moving mass m of photon is
$$m = \frac{E}{c^2} = \frac{h\upsilon}{c^2}$$
5. All photons of light of a particular frequency υ or wavelength λ have the same energy $E(= h\upsilon = \frac{hc}{\lambda})$ and momentum $p(= \frac{h\upsilon}{c} = \frac{h}{\lambda})$, whatever be the intensity of radiation.
6. Photon energy is independent of intensity of radiation.
7. Photons are not deflected by electric and magnetic fields.
8. In a photon-particle collision (such as photon-electron collision), the total energy and total momentum are conserved.
9. Number of photons emitted per second of frequency υ from a lamp of power P is,
$$n = \frac{P}{h\upsilon} = \frac{P\lambda}{hc}$$

6. DE-BROGLIE WAVES (MATTER WAVES)

Radiation has dual nature, wave and particle. The nature of experiment determines whether a wave or a particle description is best suited for understanding the experimental result. Reasoning that radiation and matter should be symmetrical

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in nature, Louis Victor de Broglie attributed a wave like character to matter (material particles). The waves associated with the moving material particles are known as matter waves or de Broglie waves.

6.1 De Broglie Wavelength

The De Broglie wavelength associated with a moving particle is related to its momentum as,

De Broglie wavelength, $\lambda = \frac{h}{p} = \frac{h}{mv}$

where, m is the mass of the particle, v is the velocity of the particle, p is the momentum of the particle.

1. De Broglie wavelength is independent of the charge and nature of the material particle.
2. In terms of kinetic energy K, De Broglie wavelength is given by,
$$\lambda = \frac{h}{\sqrt{2mK}}$$
3. If a particle of charge q is accelerated through a potential difference V, its De Broglie wavelength is given by,
$$\lambda = \frac{h}{\sqrt{2mqV}}$$
For an electron,
$$\lambda = \left(\frac{150}{V}\right)^{1/2} \text{Å}$$
4. For a gas molecule of mass m at temperature is given by,
$$\lambda = \frac{h}{\sqrt{3mkT}}$$
Where, k is the Boltzmann constant.

OBJECTIVE QUESTIONS

1. Which one of the following metals does not exhibit emission of electrons from its surface when irradiated by visible light?

(a) Rubidium (b) Sodium

(c) Cadmium (d) Caesium

Ans : SQP 2023

Certain metals like zinc, cadmium, magnesium etc. respond only to UV light to cause electron emission from its surface.

Thus (c) is correct option.

2. Matter waves are

(a) waves associated with moving particles.

(b) waves associated with stationary particles.

(c) waves associated with any charged particles.

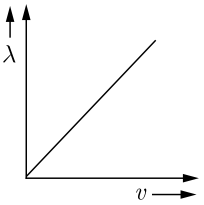
(d) waves associated with electrons only.

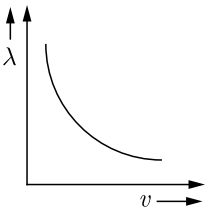
Ans : Main 2023

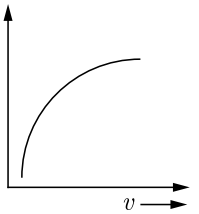
According to de Broglie's theory, every moving particle such as an electron, proton, or atom has wave-like properties called matter waves. These waves are associated with the motion of particles. Stationary particles do not produce matter waves, and the concept is not limited only to electrons or charged particles.

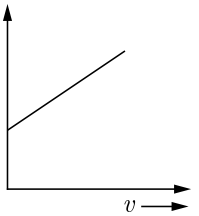
Thus (a) is correct option.

3. The graph of de-Broglie wavelength (λ) of a moving electron versus its velocity (v) is

(a) 

(b) 

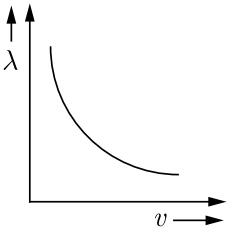
(c) 

(d) 

Ans : SQP 2023

As, $\lambda \propto \frac{1}{p}$ or for constant m, $\lambda \propto \frac{1}{v}$

So, the correct graph is

(b) 

Thus (b) is correct option.

4. De-Broglie wavelength of moving particle is λ. Its momentum is given by

(a) $\frac{h\lambda}{c}$ (b) $\frac{h}{\lambda}$

(c) $\frac{hc}{\lambda}$ (d) zero

(iii) When we listen to an orchestra, the sound waves of different instruments are produces with different characteristics but we feel pleasure why?

(iv) What is the use of principle of superposition in daily life?

Ans :

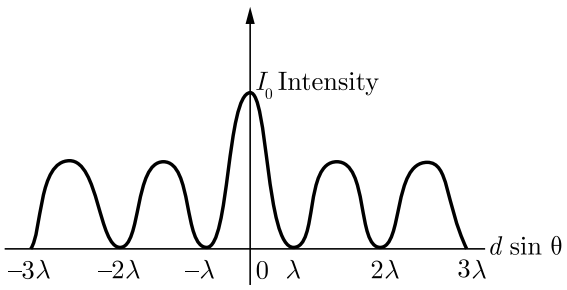
(i) When two or more waves travel simultaneously in a medium, the resultant displacement at each point of medium at any instant is equal to the vector sum of the displacements produced by the two waves separately.

(ii) The principle of superposition holds all the waves except the waves of very large amplitude, such as laser waves.

(iii) Due to the principle of superposition when we listen an orchestra, the sounds of different musical instruments are produces different characteristics of sound and by the help of this principle we feel that its a pleasure wave (sound).

(iv) The sunlight (white light) is the best example of the principle of superposition.

191. Intensity of central maxima is maximum and intensity of the secondary maxima decreases with the increase of their order. The diffraction pattern is graphically shown below in the figure. The ratio of intensities of the secondary maxima to the intensity of a central maximum are given by



$$1 : \frac{1}{21} : \frac{1}{61} : \frac{1}{121}$$

From the given ratio, it is clear that the intensity of secondary maxima is just 4% of that of central maxima.

(i) What do you mean by the term distribution of intensity?

(ii) What is the ratio of the intensity of secondary maxima and central maxima?

(iii) What happen when the screen is moved away from the plane of the slit in a single slit diffraction experiment?

(iv) What happen when the width of the slit is increased in the single slit diffraction experiment?

(v) What will be the effect on the intensity when the monochromatic light of smaller wavelength is used.

Ans :

(i) Intensity of central maxima is maximum and intensity of the secondary maxima decrease with the increase of their order. This whole phenomenon is known as "Distribution of Intensity".

(ii) The ratio of the intensity of secondary maxima and central maxima is 4%.

(iii) The angular width of central maxima is independent of the distance between slit and screen D. So, angular width remains unchanged. When the screen is moved away from the plane of the slit.

(iv) Angular width of central bright fringe will decrease when the width of slit is increased.

(v) As, $\beta \propto \lambda$, when λ is smaller, then β decreases.s

****

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12. The de-Broglie wavelength λ depends upon mass m and energy E according to the relation represented as

(a) $mE^{1/2}$ (b) $m^{1/2}E$

(c) $m^{-1/2}E^{-1/2}$ (d) $m^{-1/2}E^{1/2}$

Ans : SQP 2011

$$\text{Mass} = m$$

and $\text{Energy} = E$

de-Broglie wavelength,

$$\lambda = \frac{h}{p}$$

$$= \frac{h}{\sqrt{2mE}} \propto \frac{1}{\sqrt{mE}} \propto m^{-1/2}E^{-1/2}$$

Thus (c) is correct option.

13. Cathode rays can be deflected by

(a) electric field

(b) magnetic field

(c) both types of fields

(d) none of these fields

Ans : SQP 2009

Cathode rays are streams of negatively charged electrons. Since they carry electric charge, they can be deflected by both electric and magnetic fields. Their deflection proves that cathode rays consist of charged particles and travel in straight lines in the absence of external fields.

Thus (c) is correct option.

14. In photoelectric effect, the no. of electrons ejected per second is proportional to

(a) intensity of light

(b) wavelength of light

(c) frequency of light

(d) frequency of the metal

Ans : Main 2001

In photoelectric effect for a given photosensitive material and frequency of incident light above the threshold frequency of the material, the number of electrons ejected per second is directly proportional to the intensity of light.

Thus (a) is correct option.

15. If the intensity of light falling on a metal is increased, then

(a) K.E. of photoelectrons increases

(b) photoelectric current increases

(c) K.E. of photoelectrons decreases

(d) photoelectric current remains constant

Ans : SQP 2012

For a given photosensitive material and frequency of incident radiation above the threshold frequency, emission of photoelectrons (i.e., photoelectric current) is directly proportional to the intensity of the incident light. Therefore if the intensity of light falling on a metal is increased, then photoelectric current will also increase.

Thus (b) is correct option.

16. The kinetic energy of an electron, which is accelerated in the potential difference of 100V is

(a) 1.6×10^{-17} J (b) 1.6×10^{-14} J

(c) 1.6×10^{-10} J (d) 1.6×10^{-8} J

Ans : Main 2003

Potential difference, $V = 100$ Volt

Kinetic energy of an electron accelerating in the potential difference,

$$K = eV$$

Here, $e =$ Charge on electron equal to 1.6×10^{-19}C

Hence, $K = (1.6 \times 10^{-19}) \times 100$

$$= 1.6 \times 10^{-17}\text{J}$$

Thus (a) is correct option.

17. If a photon has velocity c and frequency ν, then which of the following represents its wavelength?

(a) $\frac{hc}{E}$ (b) $\frac{h\nu}{c}$

(c) $\frac{h\nu}{c^2}$ (d) $h\nu$

Ans : Main 2025

Velocity of photon $= c$

and Frequency $= \nu$

energy of a photon,

$$E = \frac{hc}{\lambda}$$

or $$\lambda = \frac{hc}{E}$$

(where, $\lambda =$ Wavelength of photon)

Thus (a) is correct option.

18. The number of Photons of frequency 10^{14} Hz in radiation of 6.62 J will be

(a) 10^{10} (b) 10^{15}

(c) 10^{20} (d) 10^{25}

Ans : SQP 2018

Energy, $E = 6.62$ J

Frequency, $\nu = 10^{14}$Hz

$$\text{Number of Photons} = \frac{\text{Energy}}{\text{Energy of one Photon}}$$

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Ans : **Main 2014**

For photon, $mv = \frac{h}{\lambda}$

Mass varies inversely as the wavelength. For particle $E = mc^2$, E is energy of particle if its mass is converted into energy. Both are uncorrelated.

Thus (b) is correct option.

36. **Assertion :** Photoelectric effect demonstrates the wave nature of light.

Reason : The number of photoelectrons is proportional to the frequency of light.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Main 2005, 2001**

Photoelectric effect demonstrate the particle nature of light.

The number of photo-electron is proportional to the intensity of light.

Thus (d) is correct option.

37. **Assertion :** The energy (E) and momentum (p) of a photon are related by $p = E/c$.

Reason : The photon behaves like a particle.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Main 2018**

Photon when behaves as a particle carries momentum equal to $\frac{E}{c}$.

Thus (a) is correct option.

38. **Assertion :** In photosensitive cell inert gas is used.

Reason : Inert gas in the photoemissive cell gives greater current.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **SQP 2012**

The photoemissive cell contain two electrodes are enclosed in a glass bulb which may be evacuated or contain an inert gas at low pressure. An inert gas in the cell gives greater current but causes a time lag in the response of the cell to very rapid changes of radiation which may make it unsuitable for some purpose. Thus (a) is correct option.

39. **Assertion :** In process of photoelectric emission, all emitted electrons do not have same kinetic energy.

Reason : If radiation falling on photosensitive surface of a metal consists of different wavelength then energy acquired by electrons absorbing photons of different wavelengths shall be different.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **SQP 2005**

In photoelectric emission, emitted electrons have different kinetic energies because electrons originate from different energy levels inside the metal and lose different amounts of energy before escaping. The Reason is correct for mixed wavelengths, but it is not the main explanation of the Assertion.Thus (a) is correct option.

40. **Assertion :** Photoelectric saturation current increases with the increase in frequency of incident light.

Reason : Energy of incident photons increases with increase in frequency and as a result photoelectric current increases.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

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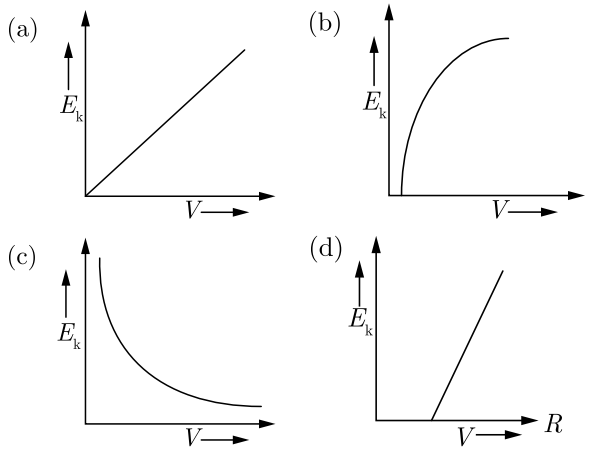
$$P = \sqrt{2mqV}$$

Hence, the de-Broglie wavelength of the particle,

$$\lambda = \frac{h}{P} = \frac{h}{\sqrt{2mqV}}$$

Thus (c) is correct option.

24. Which of the following graphs correctly represents the variation of maximum kinetic energy (E_K) of photoelectrons with the frequency (v) of the incident radiation?



Ans : SQP 2022

Maximum kinetic energy of the photoelectrons,

$$E_K = hv - \phi$$

where, v is the frequency of incident radiation.

Thus E_K versus v graph will be straight line having slope $= h$ and intercept $= \phi$ on negative Y-axis, as shown in graph (d).

Thus (d) is correct option.

25. When ultraviolet rays are incident on a metal plate, then the photoelectric effect does not occurs. It occurs by the incidence of

(a) X-rays

(b) radio wave

(c) infrared rays

(d) green house effect

Ans : Main 2017

The phenomenon of emission of electrons from a metal surface when light of sufficient frequency falls upon it, is known as photoelectric effect. We also know that photoelectrons are ejected by the radiations of short wavelength. Since, wavelength of X-rays is less than of ultraviolet rays. Therefore, photoelectric effect occurs by the incidence of X-rays.

Thus (a) is correct option.

26. The energy of emitted photo electron depends upon

(a) Intensity of light

(b) Wavelength of light

(c) Work-function of metal

(d) None of these

Ans : Main 2025

Energy of photon is given by,

$$E = h\nu$$

Where, $h =$ Planck's constant

$\nu =$ Frequency of light radiation

Since, $\nu = \frac{c}{\lambda}$

Hence, $E = \frac{hc}{\lambda}$

Here, h and c are constant $E \propto \frac{1}{\lambda}$.

Therefore the energy of emitted photo-electron depends upon the wavelength of light.

Thus (b) is correct option.

27. Mass of a photon of frequency ν is given by

(a) $m = \frac{h}{\lambda}$ (b) $m = \frac{h\nu}{c}$

(c) $m = \frac{h\nu}{c}$ (d) $m = \frac{h\nu}{c^2}$

Ans : Main 2004

Frequency of photon $= \nu$

Energy of a photon,

$$E = h\nu \quad ...(1)$$

We also know from the Einstein's relation that energy of a photon,

$$E = mc^2 \quad ...(2)$$

Equating these two equations of energies, we get

$$h\nu = mc^2$$

or $$m = \frac{h\nu}{c^2}$$

where, $m =$ mass of the photon

and $c =$ velocity of light

Thus (d) is correct option.

28. If the kinetic energy of an electron doubles, its de-Broglie's wavelength changes by a factor

(a) 2 (b) $\sqrt{2}$

(c) $\frac{1}{2}$ (d) $\frac{1}{\sqrt{2}}$

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$$= \frac{6.62}{h\nu}$$

$$= \frac{6.62}{6.62 \times 10^{-34} \times 10^{14}}$$

$$= 10^{20}$$

Thus (c) is correct option.

19. If an electron of mass m and charge e is accelerated from rest through a potential difference V in vacuum, then its final velocity will be

(a) $\frac{eV}{2m}$ (b) $\frac{eV}{m}$

(c) $\sqrt{\frac{2eV}{m}}$ (d) $\sqrt{\frac{eV}{m}}$

Ans : Main 2024, 2006

Mass of electron $= m$

Charge $= e$

and Potential difference $= V$

kinetic energy of an electron

$$= \frac{1}{2}mv^2 = eV$$

$$v = \sqrt{\frac{2eV}{m}}$$

(where, $v =$ Final velocity of electron)

Thus (c) is correct option.

20. In photoelectric effect experiment, the slope of the graph of the stopping potential versus frequency gives the value of

(a) $\frac{h}{e}$ (b) h

(c) $\frac{e}{h}$ (d) $\frac{hc}{e}$

Ans : Main 2020

From Einstein's photoelectric equation,

$$hv = V_0 e + W_0$$

$$V_0 = \frac{hv}{e} - \frac{W_0}{e} \quad ...(1)$$

Equation of line,

$$y = mx + c \quad ...(2)$$

By comparing Eqs. (1) and (2), we get slope $m = \frac{h}{e}$

Thus (a) is correct option.

21. If momentum of a particle is doubled, then its de-Broglie's wavelength will

(a) be half

(b) be two times

(c) be four times

(d) remain unchanged

Ans : Main 2008, 2005

Final momentum of particle,

$$p_2 = 2p_1$$

(where, $p_1 =$ Initial momentum of particle)

De-Broglie's wavelength of particle,

$$\lambda = \frac{h}{mv} = \frac{h}{p} \propto \frac{1}{p}$$

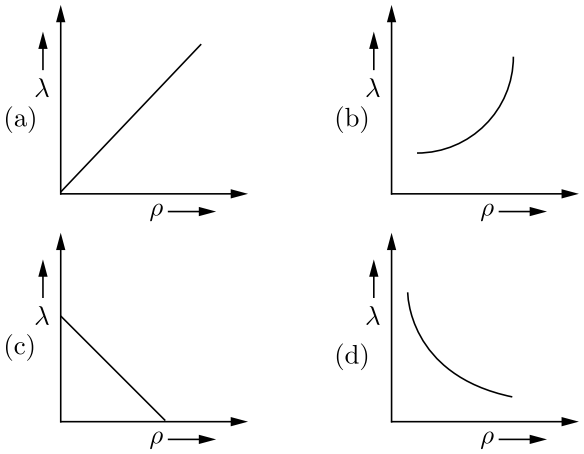
Where $h =$ plank constant

Therefore, $\frac{\lambda_1}{\lambda_2} = \frac{p_2}{p_1} = \frac{2p_1}{p_1} = 2$

$$\lambda_2 = \frac{\lambda_1}{2}$$

Thus (a) is correct option.

22. Which one of the following graphs in figure represents variation of de-Broglie wavelength (λ) of a particle having linear momentum (p)?



Ans : Main 2011

As, $\lambda \propto \frac{1}{p}$. The correct graph is

Thus (d) is correct option.

23. A particle of mass m and charged q is accelerated through a potential V. The De-Broglie wavelength of the particle will be :

(a) $\frac{Vh}{\sqrt{2qm}}$ (b) $\frac{q}{\sqrt{2mV}}$

(c) $\frac{h}{\sqrt{2qmV}}$ (d) $\frac{mh}{\sqrt{2qV}}$

Ans : Main 2018, 2011

A particle of mass m and charged q is accelerated through a potential V.

Kinetic energy gained by the particle,

$$K = \frac{1}{2}mv^2 = \frac{P^2}{2m}$$

Work done on electron $= qV$.

Hence, $\frac{P^2}{2m} = qV$

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Since both the beams of light are equally energetic,

Therefore, $n_1 h\nu_1 = n_2 h\nu_2$

or $\frac{n_1}{n_2} = \frac{\nu_2}{\nu_1}$

Where, h = Planck's constant

Thus (c) is correct option.

ASSERTION AND REASON

DIRECTION : These questions consist of two statements, each printed as Assertion and Reason. While answering these questions, you are required to choose any one of the following five responses.

32. **Assertion :** Photo-sensitivity of a metal is high if its work function is small.

Reason : Work function $= hf_0$ where f_0 is the threshold frequency.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Main 2016**

The photo-sensitivity of a metal is high when its work function is small. Work function of a metal depends not on the threshold frequency but on the nature of the metal.

Thus (b) is correct option.

33. **Assertion :** Kinetic energy of photo electrons emitted by a photosensitive surface depends upon the intensity of incident photon.

Reason : The ejection of electrons from metallic surface is possible with frequency of incident photon below the threshold frequency.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Main 2010**

Intensity of incident photon decides the number of electrons ejected and not the kinetic energy.

Ejection of electron from metallic surface is possible only when frequency of incident photon is more than threshold frequency.

Thus (d) is correct option.

34. **Assertion :** If the speed of charged particle increases both the mass as well as charge increases.

Reason : If $m_0 =$ rest mass and m be mass at velocity v then

$$m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

where c = speed of light.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) The Assertion is incorrect but the Reason is correct.

Ans : **SQP 2017**

When speed of particle increases, the mass increases as

$$m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$ charge does not alter

Thus (d) is correct option.

35. **Assertion :** Mass of moving photon varies inversely as the wavelength.

Reason : Energy of the particle = mass $\times$ (speed of light)^2

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

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48. Define the term 'intensity of radiation' in photon picture.

Ans : **SQP 2017**

The amount of light energy or photon energy incident per metre square per second is called intensity of radiation.

49. Define the term 'threshold frequency' in relation for photoelectric effect.

Ans : **SQP 2021**

Threshold frequency is defined as the minimum frequency of incident radiation which can cause photoelectric emission. It is different for different metal.

50. What do you mean by stopping potential.

Ans : **Comp 2025, 2011**

The particular value of negative potential V_0 at which photoelectric current becomes zero that is known as stopping potential.

51. Define intensity of radiation on the basis of photon picture of light. Write its SI unit.

Ans : **SQP 2017**

The amount of light energy or photon energy incident per metre square per second is called intensity of radiation. Its SI unit is $\frac{\mathrm{W}}{\mathrm{m}^2}$ or $\mathrm{j/s\,m^2}$.

52. In photoelectric effect, what is meant by the term threshold frequency?

Ans : **Main 2011, 2001**

For a given material, the exists a certain minimum frequency of the incident retaliation below which no emissions of photoelectrons takes place. This frequency is called threshold frequency.

53. Explain the nature of the curves on the basis of Einstein's equation.

Ans : **Main 2017**

As per Einstein's equation :

(i) The stopping potential is same for I_1 and I_2 as they have the same frequency.

(ii) The saturation currents are as shown in figure because $I_1 > I_2 > I_3$.

54. Why does thermionic emission take place from a metal surface only?

Ans : **SQP 2010**

Thermionic emission take place from a metal surface because the metal has free electron. When a metal is heated, its free electrons get sufficient thermal energy and they can overcome surface barrier.

55. What is de-Broglie wave? Write an expression for its wavelength.

Ans : **Main 2024, 2013**

The wave which is associated with movable matter particle is known as the de-Broglie wave or matter wave. The wavelength of de-Broglie wave is given by following expression:

Wavelength, $\lambda = \frac{h}{p} = \frac{h}{mv}$

56. (where, p is momentum) In photoelectric effect, why should the photoelectric current increase as the intensity of monochromatic radiation incident on a photosensitive surface is increased? Explain.

Ans : **Main 2014**

The photoelectric current increases proportionally with the increase in intensity of incident radiation. Larger the intensity radiation, larger is the number of incident photons and hence larger is the number of electrons ejected from the photosensitive surface.

57. tate de-Broglie hypothesis.

Ans : **Main 2022 Sem-II , 2020, 2018**

According to de-Broglie, a wave is associated with moving material particle which controls the particle in every aspect. The wave associated with the moving material particle is called matter wave or de-Broglie wave and its wavelength is called de-Broglie wavelength. It is

$$\lambda = \frac{h}{mv}$$

58. What is the relation between wavelength and momentum of moving electrons?

Ans : **Main 2025, 2013**

The relation between wavelength and momentum of moving electrons is given by de-Broglie relation,

$$\lambda = \frac{h}{p}$$

Where, λ = wavelength,

h = Planck's constant and

$p = mv$ = Momentum of electrons

59. Show graphically the variation of the de-Brogile wavelength (λ) with the potential (V) through which an electron is accelerated from rest.

Ans : **Main 2020, Comp 2019**

$\lambda \propto \frac{1}{V}$, so graph is shown in figure below :

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(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Main 2010**

The saturation current in the photoelectric effect depends on the intensity of incident light, not on its frequency. Increasing frequency increases the energy of photons, which raises the kinetic energy of emitted electrons, but it does not increase the photoelectric current. Hence, both the Assertion and Reason are incorrect.

Thus (d) is correct option.

41. **Assertion :** The photoelectrons produced by a monochromatic light beam incident on a metal surface have a spread in their kinetic energies.

Reason : The work function of the metal is its characteristics property.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Main 2003**

Photoelectrons emitted by monochromatic light have different kinetic energies because electrons inside the metal possess different initial energies. The work function is indeed a characteristic property of the metal, but this fact does not explain the spread in kinetic energies of emitted electrons.

Thus (b) is correct option.

42. **Assertion :** The photoelectrons produced by a monochromatic light beam incident on a metal surface, have a spread in their kinetic energies.

Reason : The work function of the metal varies as a function of depth from the surface.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Main 2007**

Electrons being emitted as photoelectrons have different velocities. Actually all the electrons do not occupy the same level of energy but they occupy continuous band and levels. So, electrons being knocked off from different levels come out with different energies. Work function is the energy required to pull the electron out of metal surface. Naturally electrons on the surface will require less energy to be pulled out hence will have lesser work function as compared with those deep inside the metal. So, assertion and reason are correct and reason correctly explains the assertion.

Thus (a) is correct option.

ONE MARK QUESTIONS

43. Name the phenomenon which shows the quantum nature of electromagnetic radiation.

Ans : **SQP 2020**

Photoelectric effect.

44. Define the term intensity of radiation in terms of photon picture of light.

Ans : **SQP 2009**

The number of photons incident normally per unit area per unit time is determined the intensity of radiations.

45. Name the phenomena or experiment which proves particle nature of electromagnetic radiations.

Ans : **Main 2013**

Photoelectric effect is the phenomena which proves particle nature of electromagnetic radiation.

46. How can the work function of tungsten be increased?

Ans : **Main 2007, 2001**

Work function of tungsten can be increased by coating it with thorium whose work function is lower than tungsten.

47. Give Einstein's equation for photoelectric emission. What do symbol stands for?

Ans : **Main 2004**

$$K_{\max} = eV_0 = hv - \phi_0.$$

Where, h = Plank Constant and other symbol have own meanings.

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Ans : **Comp 2008**

Final kinetic energy of electron,

$$E_2 = 2E_1$$

(where, E_1 = Initial kinetic energy of electron)

de-Broglie's wavelength of an electron,

$$\lambda = \frac{h}{mv}$$

$$= \frac{h}{\sqrt{2mE}} \propto \frac{1}{\sqrt{E}}$$

Therefore, $\frac{\lambda_1}{\lambda_2} = \sqrt{\frac{E_2}{E_1}}$

$$= \sqrt{\frac{2E_1}{E_1}} = \sqrt{2}$$

or $\lambda_2 = \frac{\lambda_1}{\sqrt{2}}$

Hence, de-Broglie's wavelength of an electron changes by the factor $\frac{1}{\sqrt{2}}$.

Thus (d) is correct option.

29. If a radiation of energy E falls normally on a perfectly reflecting surface, then the momentum transferred to the surface is

(a) Ec (b) Ec^2

(c) $\frac{E}{c^2}$ (d) $\frac{2E}{c}$

Ans : **SQP 2004**

Energy of radiation $= E$

Velocity of radiation before reflection,

$$v_1 = c$$

Where, c = Velocity of light

Since, the surface is perfectly reflecting, therefore velocity of radiation after reflection,

$$v_2 = -c$$

(minus sign due to opposite direction)

We also know that momentum of radiation before reflection,

$$p_1 = \frac{E}{c}$$

and momentum of radiation after reflection,

$$p_2 = \frac{E}{(-c)} = -\frac{E}{c}$$

Therefore, momentum transferred to the surface

$$= p_1 - p_2$$

$$= \frac{E}{c} - \left(-\frac{E}{c}\right)$$

$$= \frac{2E}{c}$$

Thus (d) is correct option.

30. The energy that should be added to an electron, to reduce its de-Broglie's wavelength from 10^{-10}m to 0.5×10^{-10} m will be

(a) equal to the initial energy

(b) twice the initial energy

(c) three times the initial energy

(d) four times the initial energy

Ans : **SQP 2017, 2012**

Initial de-Broglie's wavelength,

$$\lambda_1 = 10^{-10}\ \text{m}$$

and final de-Broglie's wavelength,

$$\lambda_2 = 0.5 \times 10^{-10}\ \text{m}$$

Velocity of electron,

$$v = \frac{h}{m\lambda}$$

and kinetic energy of electron,

$$E = \frac{1}{2}mv^2$$

$$= \frac{1}{2}m\left(\frac{h}{m\lambda}\right)^2$$

$$= \frac{h^2}{2m\lambda^2} \propto \frac{1}{\lambda^2}$$

Therefore, $\frac{E_2}{E_1} = \left(\frac{\lambda_1}{\lambda_2}\right)^2$

$$= \left(\frac{10^{-10}}{0.5 \times 10^{-10}}\right)^2 = 4$$

$$E_2 = 4E_1$$

Thus (d) is correct option.

31. There are n_1 photons of frequency ν_1 in a beam of light. In an equally energetic beam, there are n_2 photons of frequency ν_2. Their correct relation is

(a) $\frac{n_1}{n_2} = 1$ (b) $\frac{n_1}{n_2} = \frac{\nu_1}{\nu_2}$

(c) $\frac{n_1}{n_2} = \frac{\nu_2}{\nu_1}$ (d) $\frac{n_1}{n_2} = \frac{\nu_1^2}{\nu_2^2}$

Ans : **SQP 2017**

In First Beam

No. of photons $= n_1$

Frequency of each photon $= \nu_1$

In Second Beam, No. of photons $= n_2$

and Frequency of each photon $= \nu_2$

Energy of n_1 photons in first beam of light,

$$E_1 = n_1 h\nu_1$$

Similarly, energy of n_2 photons in second beam of light,

$$E_2 = n_2 h\nu_2$$

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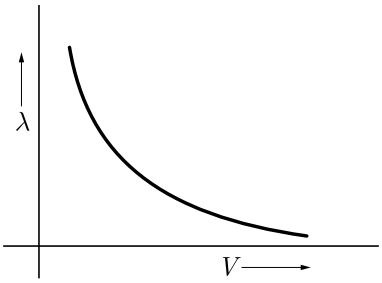
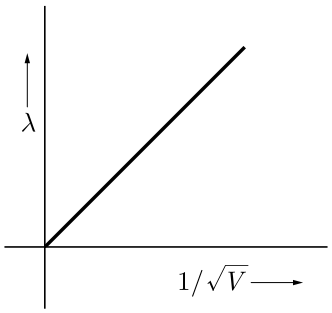


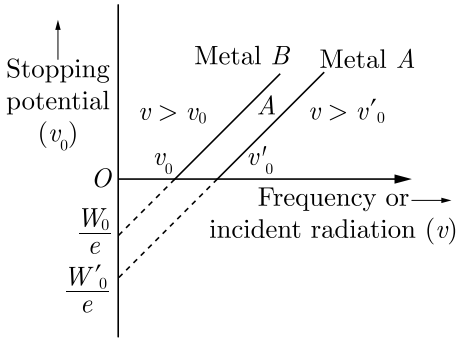
60. Show on a graph variation of the de-Broglie wavelength (λ) associated with the electron versus $1\sqrt{V}$, where V is the accelerating potential for the electron.

Ans : **SQP 2019**

$$\lambda = \frac{h}{\sqrt{2meV}}$$



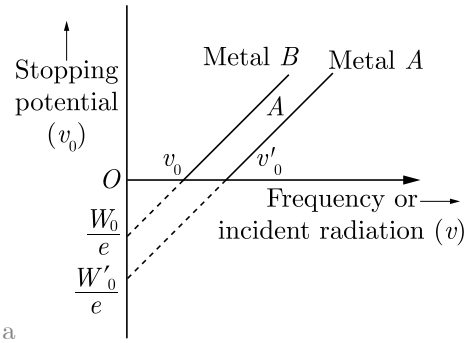
61. The graph shows the variation of stopping potential with frequency of incident radiation for two photosensitive metals A and B. Which one of the two has higher value of work function? Justify your answer.



Ans : **Comp 2021, 2017**

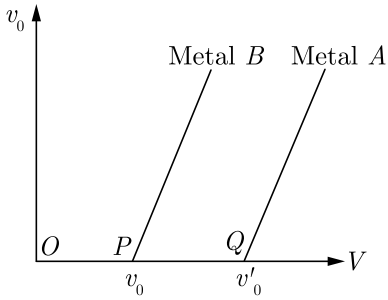
Metal A has higher value of work function because and the intercept of the line of the given graph depends on work function.

62. The graph shows variation of stopping potential V_0 versus frequency of incident radiation v for two photosensitive metals A and B which one of the two metals has higher threshold frequency and why?



a

Ans : **Main 2021**



As, $OQ > OP$

Hence, $v'_0 > v_0$

So, the threshold frequency of metal A is greater than metal B.

TWO MARKS QUESTIONS

63. What is meant by work function of a metal? How does the value of work function influence the kinetic energy of electrons liberated during photo-electron emission?

Ans : **SQP 2016**

The minimum energy required to free an electron from metallic surface is called the work function.

Smaller the work function, larger the kinetic energy of emitted electron.

64. Why is the belt of a Van de Graaff generator made of insulating material?

Ans : **SQP 2011**

Because this charges taken by belt do not spread out but it resides on same place. Charges are send by the belt to the pointed conductor. If the belt is conductor material then charges spread out on the whole belt and the system does not run systematically.

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65. Define the following with reference to photoelectric effect.

(i) Threshold frequency f_0

(ii) Stopping potential V_s

Ans : **Main 2019, 2018**

(i) The lowest frequency of light which can emit photoelectrons from a material is called the threshold frequency f_0.

(ii) The negative potential at which the photoelectric current becomes zero is called stopping potential V_s.

66. When the electron orbiting in hydrogen atom in its ground state moves to the third excited state, show how the de-Broglie wavelength associated with it would be affected.

Ans : **SQP 2018**

De-Broglie wavelength

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

$$\lambda \propto \frac{1}{v}$$

Also, $$v \propto \frac{1}{n}$$

$$\lambda \propto n$$

Hence, de-Broglie wavelength will increase.

67. Why photoelectric effect cannot be explained on the basis of wave nature of light? Give reasons.

Ans : **SQP 2024, 2016**

The photoelectrons effect cannot be explained on the basis of wave nature of light because wave nature of radiation cannot explain the following.

(a) The instantaneous ejection of photoelectrons.

(b) The existence of threshold frequency for a metal surface.

(c) The fact that kinetic energy of the emitted electrons is independent of the intensity of light and depends upon its frequency.

68. Two monochromatic beams, one red and the other blue, have the same intensity in which case

(i) the number of photons per unit area per second is larger,

(ii) the maximum kinetic energy of the photoelectrons is more? Justify your answer.

Ans : **Main 2016, 2014**

(i) Red light, because the energy of red light is less than that of blue light

$$(h\nu)_R < (h\nu)_B$$

(ii) Blue light, because the energy of blue light is greater than that of red light.

$$(h\nu)_B > (h\nu)_R$$

69. Write the expression for the de-Broglie wavelength associated with a charged particle having charge q and mass m, when it is accelerated by a potential.

Ans : **Comp 2017**

A charged particle having charge q and mass m, then kinetic energy of the particle is equal of the particle is equal to the work done on it by the electric field.

i.e., $$K = qV$$

$$\frac{1}{2}mv^2 = qV$$

$$\frac{p^2}{2m} = qV$$

$$p = \sqrt{2mqV}$$

70. Discuss briefly how wave theory of light cannot explain these features.

Ans : **Main 2014, 2009**

These features cannot be explained in the wave theory of light because wave nature of radiation cannot explain the following.

(a) The instantaneous ejection of the photoelectrons.

(b) The existence of threshold frequency for a metal surface.

(c) The fact that kinetic energy of the emitted electrons is independent of the intensity of light and depend upon its frequency.

71. Write three characteristic features, in photoelectric effect which cannot be explained on the basis of wave theory of light, but can be explained only using Einstein's equation.

Ans : **Comp 2015**

The three characteristic features which cannot be explained by wave theory are as follows :

1. Kinetic energy of emitted electrons is found to be independent of the intensity of incident light.
2. There is no emission of electrons if frequency of incident light is below a certain frequency (threshold frequency).
3. Photoelectric effect is an instantaneous process.

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72. Write the basic features of photon picture of electromagnetic radiation on which Einstein's photoelectric equation is based.

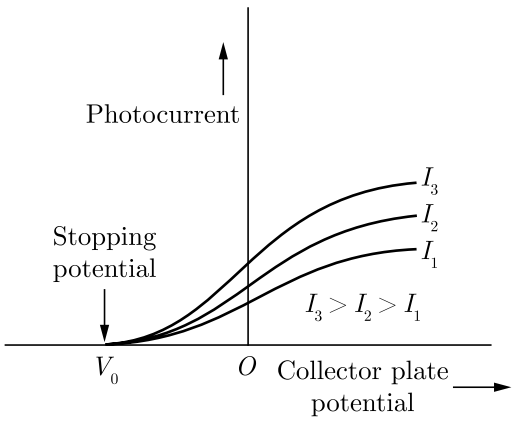
Ans : **Main 2025, 2014**

Features of the photons are as :

1. Photons are particles of light having energy $E = hv$ and momentum $p = \frac{h}{\lambda}$, where, h is Planck's constant.
2. Photons travel with the speed of light in vacuum, independent of the frame of reference.
3. Intensity of light depends on the number of photons crossing unit area in a unit time.

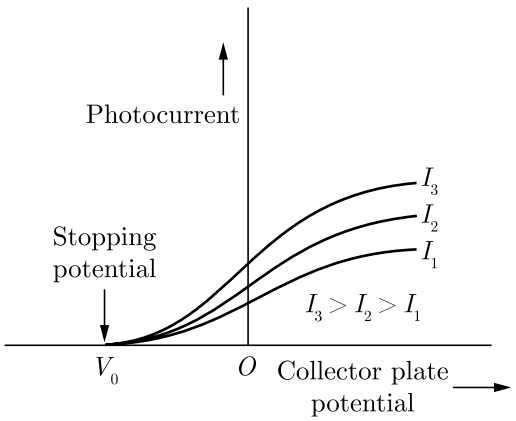
73. Show the variation of photo-current with collector plate potential for different intensity but same frequency of incident radiation.

Ans : **Main 2018, 2011**



74. Show the variation of photo-current with collector plate potential for different intensity but same frequency of incident radiation.

Ans : **Main 2018, 2011**



75. For each of the following, state one phenomenon in which

(i) particles behave like waves.

(ii) waves behave like particles.

Ans : **SOP 2018**

(i) Interference of light is the phenomena in which particles behave like waves. In this phenomena, when two or more waves of the same frequency and having zero or constant phase difference are travelling in same direction superimpose on each other.

(ii) Photoelectric effect is the phenomena is which waves behaves like particles. In this phenomena, when a suitable frequency of light, falls on the metal surface, electrons are emitted from metal surface.

76. A proton and an electron have same velocity. Which one has greater de-Broglie wavelength and why?

Ans : **Main 2019**

De-Broglie wavelength (λ) is given as $\lambda = \frac{h}{mv}$

$$v_p = v_e$$

Where, v_p = velocity of proton

and v_e = velocity of electron

Since, $m_p > m_e$

From the given relation

$$\lambda \propto \frac{1}{m},$$

Hence $\lambda_p < \lambda_e$

Thus, electron has greater de-Brogile wavelength, if accelerated with same speed.

77. Two metals A and B have work functions 4 eV and 6 eV, respectively. Which metal has lower threshold wavelength for photoelectric effect?

Ans : **Main 2016**

work function of metal A, $\phi_{OA} = 4$ eV

Work function of metal B, $\phi_{OB} = 6$ eV

Therefore, threshold wavelength of metal A,

$$\lambda_{OA} = \frac{hc}{\phi_{OA}} = \frac{hc}{4} \quad ...(1)$$

Similarly, threshold wavelength of metal B,

$$\lambda_{OB} = \frac{hc}{\phi_{OB}} = \frac{hc}{6}$$

On comparing Eqs. (1) and (2), we can say that

$$\lambda_{OA} > \lambda_{OB}$$

i.e. Threshold wavelength of metal A is greater than that of metal B.

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Ans : **SQP 2015**

In photoelectric effect, an electron absorbs a quantum of energy hv of radiation, which exceeds the work function, an electron is emitted with maximum kinetic energy.

$$E_{K\max} = hv - W$$

(i) No, all electrons are bound with different forces in different layers of the metal. So, more tightly bound electron will emerge with less kinetic energy. Hence, all electrons do not have same kinetic energy.

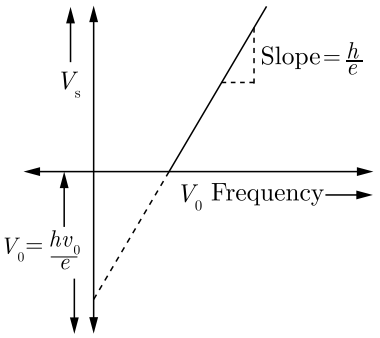
(ii) No, because an electron cannot emit out if quantum energy hv is less than the work function of the metal. The K_E depends on energy of each photon.

(iii) Number of emitted photoelectrons depends on the intensity of the radiations provided the quantum energy hv is greater than the work function of the metal.

104. Plot a labelled graph of (V_s), where V_s is stopping potential of photoelectrons versus frequency v of incident radiation. How will you use this graph to determine the value of Planck's constant? Explain.

Ans : **SQP, 2018, 2017, 2009**

Graph for V_s and v is as follows



As from the graph it is clear that slope of the graph is given by

$$\text{Slope} = \frac{h}{e}$$

where, h = Planck's constant

and e = charge on an electron.

Now from Einstein's photoelectric equation

$$K_{\max} = hv - \phi$$

$$eV_0 = hv - \phi$$

$$V_0 = \left(\frac{h}{e}\right)v - \frac{\phi}{e}$$

Comparing this equation with $y = mx + c$,

Slope of (V_0, v) graph $= \frac{h}{e}$.

So, Planck's constant

$$h = \text{slope } (V_0, v) \text{ graph} \times e$$

105. Define the terms :

(i) 'cut-off voltage' and

(ii) 'threshold frequency' in relation to the phenomenon of photoelectric effect.

Using Einstein's photoelectric equation show how the cut-off voltage and threshold frequency for a given photosensitive material can be determined with the help of a suitable plot/graph.

Ans : **SQP 2012, 2019**

(i) Cut-off or stopping potential is that minimum value of negative potential at anode which just stops the photoelectric current.

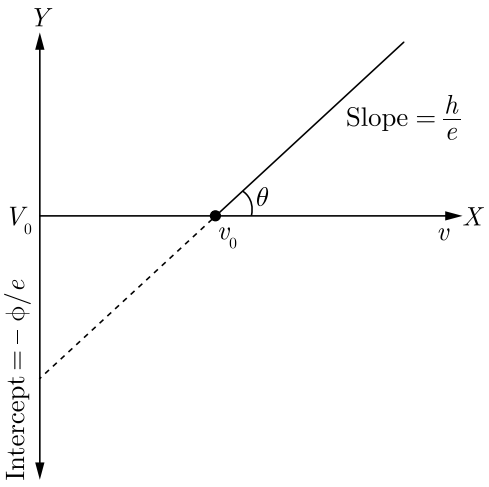
(ii) For a given material, there is a minimum frequency of light below which no photoelectric emission will take place, this frequency is called as threshold frequency.

$$E_{K_{\max}} = \frac{hc}{\lambda} - \phi = hv - hv_0$$

$$eV_0 = hv - hv_0$$

$$V_0 = \frac{h}{e}v - \frac{h}{e}v_0$$

Clearly, $V_0 - v$ graph is a straight line.



106. Explain briefly the reasons why wave theory of light is not able to explain the observed features of photo-electric effect.

Ans : **Main 2012**

The observed characteristics of photoelectric effect could not be explained on the basis of wave theory of light due to the following reasons :

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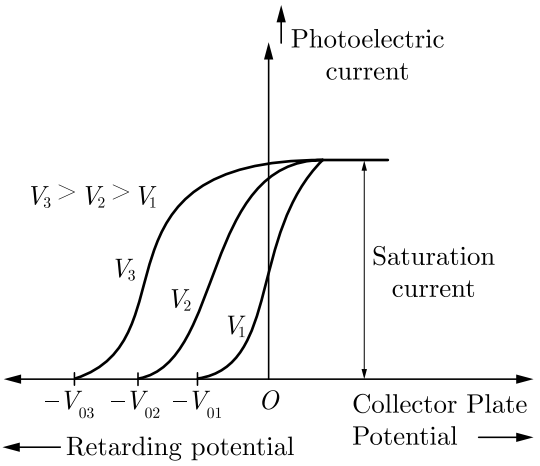

84. A proton and a deutron are accelerated through the same accelerating potential. Which one of the two has.

1. Greater value of de-Broglie wavelength associated with it.
2. Less momentum?

Give reasons to justify your answer.

Ans : **Main 2013**

1. De-Broglie wavelength,

$$\lambda = \frac{h}{\sqrt{2mqV}}$$

Here, V is same for proton and deutron.
As mass of proton $<$ mass of deutron and $q_p = q_d$.
Therefore, $\lambda_p > \lambda_d$ for same accelerating potential.

2. Momentum $= \frac{h}{\lambda}$.

Therefore, $\lambda_p > \lambda_d$

So, momentum of proton will be less than that of deuteron.

85. Show mathematically how Bohr's postulate of quantization of orbital angular momentum in hydrogen atom is explained by de-Broglie's hypothesis.

Ans : **SQP 2024, 2016**

According to de-Broglie's hypothesis,

$$\lambda = \frac{h}{mv} \quad ...(1)$$

According to de-Broglie's condition of stationary orbits, the stationary orbit are those which contain complete de-Broglie wavelength.

$$2\pi r = n\lambda \quad ...(2)$$

Substituting value of λ from (1) in (2), we get

$$2\pi r = n\frac{h}{mv}$$

$$mvr = n\frac{h}{2\pi} \quad ...(3)$$

This is Bohr's postulate of quantisation of energy levels.

86. When an electron in hydrogen atom jumps from the third excited state to the ground state. How would the de-Broglie wavelength associated with the electron charge? Justify your answer.

Ans : **Main 2011, 2009**

We know that,

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

$$mv = \frac{h}{\lambda}$$

$$mvr = \frac{hr}{\lambda}$$

$$\lambda = \frac{2\pi}{nh} \times hr$$

$$= \frac{2\pi r}{n}$$

As, $r \propto n^2$

$$\lambda \propto \frac{1}{n}(n^2) = n$$

Thus, we can say that,

$$\frac{\lambda_3}{\lambda_1} = \frac{3}{1} \text{ or } \lambda_1 = \frac{\lambda_3}{3}$$

Thus, wavelength decreases 3 times as an electron jumps from third excited state to the group state.

87. A proton and an electron have same kinetic energy. Which one has greater de-Broglie wavelength and why?

Ans : **Main 2015**

De-Broglie wavelength,

$$\lambda = \frac{h}{p}$$

$$= \frac{h}{\sqrt{2mK}}$$

Where, $K = E_K$

For given KE, $\lambda \propto \frac{1}{\sqrt{m}}$

Electron have smaller mass, $\lambda_e > \lambda_p$ [So $m_e < m_p$].
For given kinetic energy, electrons have greater wavelength as these have smaller mass.

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$$\frac{1}{2}mv_2^2 = h(5f - f)$$

$$\frac{1}{2}mv_2^2 = 4hf \quad ...(2)$$

Dividing (1) by (2), we get

$$\left(\frac{v_1}{v_2}\right)^2 = \frac{1}{4}$$

$$\frac{v_1}{v_2} = \frac{1}{2}$$

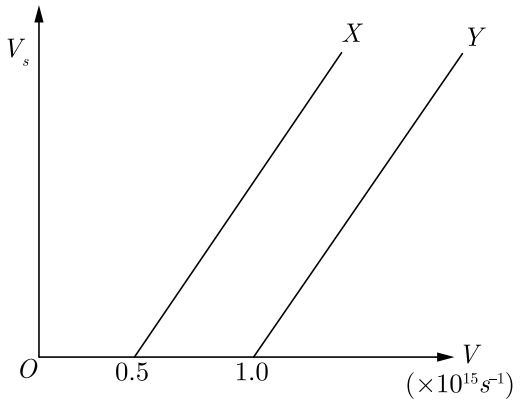
Hence, $v_1 : v_2 = 1 : 2$

109. The following graph shows the variation of stopping potential V_s with the frequency (v) of the incident radiation for two photosensitive metals X and Y.

(i) Which of the metals has larger threshold wavelength? Give reason.

(ii) Explain giving reason which metal gives out electrons having larger kinetic energy, for the same wavelength of the incident radiation.

(iii) If the distance between the light source and metal X is halved, what will be the kinetic energy of electrons emitted due to this change? Give reason.



Ans : **Main 2025, 2011**

(i) Threshold frequency of $X = 0.5 \times 10^{15} s^{-1}$

Threshold frequency of $Y = 1.0 \times 10^{15} s^{-1}$

As threshold wavelength is inversely proportional to threshold frequency, so metal X has larger threshold wavelength.

(ii) Kinetic energy $E_K = \frac{hc}{\lambda} - hv_0$

As threshold frequency v_0 is smaller for X, so for same wavelength of incident radiation, kinetic energy is larger for metal X.

(iii) If the distance between light source and metal X is halved, the intensity of incident radiation becomes one fourth $\left(I \propto \frac{1}{r^2}\right)$ but kinetic energy of photoelectrons is independent of intensity, so kinetic energy of photoelectrons remains unchanged.

110. Write Einstein's photoelectric equation. State clearly the three salient features observed in photoelectric effect which can explain on the basis of this equation.

The maximum kinetic energy of the photoelectrons gets doubled when the wavelength of light incident on the surface changes from λ_1 to λ_2. Derive the expressions to the threshold wavelength λ_0 and work function for the metal surface.

Ans : **Comp 2014**

Einstein's photoelectric equation is $E_K = hv - W$ for a single photon ejecting a single electron.

(i) **Explanation of frequency law-** When frequency of incident photon (v), increases, the kinetic energy of emitted electron increases. Intensity has no effect on kinetic energy of photoelectrons.

(ii) **Explanation of intensity law-** When intensity of incident light increases, the number of incident photons increases, as one photon ejects one electron; the increase in intensity will increase the number of ejected electrons. In other words, photo-current will increase with increase of intensity. Frequency has no effect on photo-current.

(iii) **Explanation of no time lag law-** When the energy of incident photon is greater than work function, the photo-electron is immediately ejected, Thus, there is no time lag between incidence of light and emission of photoelectrons.

For wavelength λ_1,

$$\frac{hc}{\lambda_1} = \phi_0 + E_K = \phi_0 + eV_0 \quad ...(1)$$

Where, $E_K = eV_0$

For wavelength λ_2,

$$\frac{hc}{\lambda_2} = \phi_0 + 2eV_0 \quad ...(2)$$

because E_K is doubled

From equations (1) and (2), we get

$$\frac{hc}{\lambda_2} = \lambda_2 + 2\left(\frac{hc}{\lambda_1} - \phi_0\right)$$

$$= \phi_0 + \frac{2hc}{\lambda_1} - 2\phi_0$$

$$\phi_0 = \frac{2hc}{\lambda_1} - \frac{hc}{\lambda_2}$$

For threshold wavelength λ_0, kinetic energy

$E_K = 0$ and work function ϕ_0

$$= \frac{hc}{\lambda_0}$$

$$\frac{hc}{\lambda_0} = \frac{2hc}{\lambda_1} - \frac{hc}{\lambda_2}$$

NODIA

91. Use de-Broglie's hypothesis to write the relation for nth radius of Bohr orbit in terms of Bohr's quantization condition of orbital angular momentum.

Ans : **Main 2010**

According to de-Broglie's hypothesis,

$$\lambda = \frac{h}{p} = \frac{h}{mv_n} \quad ...(1)$$

According to de-Broglie's condition of stationary orbits, the stationery orbits are those which contain complete de-Broglie wavelength.

$$2\pi r_n = n\lambda : n = 1, 2, 3 \quad ...(2)$$

Substituting value of λ from (1) in (2), we get

$$2\pi r_n = n\frac{h}{mv_n}$$

$$r_n = \frac{nh}{2\pi mv_n}$$

92. Write the relationship of de-Broglie wavelength λ associated with a particle of mass m in terms of its kinetic energy E.

Ans : **Comp 2010, 2013**

Kinetic energy, $E_K = \frac{p^2}{2m}$

Where, p = momentum

m = mass

and E_K = kinetic energy

$p = \sqrt{2mE_K}$

de-Broglie wavelength,

$$\lambda = \frac{h}{p}$$

where, $p = \sqrt{2mE_K}$

Hence, $\lambda = \frac{h}{\sqrt{2mE_K}}$

93. Describe briefly three experimentally observed features in the phenomenon of photoelectric effect.

Ans : **Comp 2010**

Three experimentally observed features in the phenomenon of photoelectric effect.

(a) **Intensity-** When intensity of incident light increases as one photon ejects one electron, the increase in intensity will increase the number of ejected electrons. Frequency has no effect on photoelectrons.

(b) **Frequency-** When the frequency of incident photon increase, the kinetic energy of the emitted electrons increases, intensity has no effect on kinetic energy of photoelectrons.

(c) **No time lag-** When energy incident photon is greater than the work function, the photoelectrons is immediately ejected. Thus, there is no time lag between the incidence of light and emission of photoelectrons.

94. Write Einstein's photoelectric equation and point out any two characteristic properties of photons on which this equation is based.

Ans : **SQP 2013**

If radiation of frequency ν greater than threshold frequency (ν_0) irradiate the metal surface, electrons emitted out from the metal. So Einstein's photoelectric equation can be given as,

$$E_{max} = \frac{1}{2}m\nu_{max}^2$$

$$= h\nu - h\nu_0$$

Characteristic properties of photons :

1. Energy of photon is directly proportional to the frequency (or inversely proportional to the wavelength).
2. In photon-electron collision, total energy and momentum of the system of two constituents remains constant.
3. In the interaction of photons with the free electrons, the entire energy of photon is absorbed.

95. Why photoelectric effect cannot be explained on the basis of wave nature of light?

Ans : **Main 2025, 2021**

According to wave theory, light is an electromagnetic wave consisting of electric and magnetic fields with continuous distribution of energy over the region over which the wave extends. This theory failed to explain the following experimental facts:

1. A higher intensity of incident radiation should liberate photoelectrons of higher kinetic energy. But K_{max} is found to be independent of intensity.
2. No matter what the frequency of incident radiation is, a light wave of sufficiently high intensity should be able to eject the electrons from the metal surface. Thus the wave theory fails to explain the existence of threshold frequency.
3. An electron intercepts a very small amount of the energy of a light wave and so it should require a finite time to escape from metal surface. But actually, the emission is almost instantaneous.

NODIA

78. State how de-Broglie wavelength (λ) of moving particles varies with their linear momentum (p).

Ans : **Main 2015**

According to Planck's quantum theory, the energy of the photon is

$$E = h\nu = \frac{hc}{\lambda} \quad ...(1)$$

According to Einstein's theory, the energy of the photon is

$$E = mc^2 \quad ...(2)$$

From Eqs. (1) and (2), we get

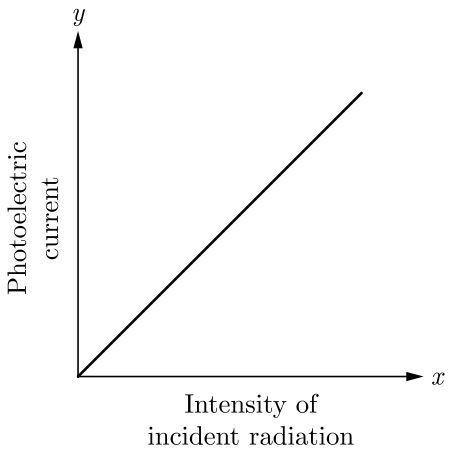
$$\lambda = \frac{h}{mc} \text{ or } \lambda = \frac{h}{p}$$

where, p is momentum of a photon.

79. Show on a plot the nature of variation of photoelectric current with the intensity of radiation incident on a photosensitive surface.

Ans : **Comp 2019**

Graph of variation of photoelectric current with the intensity of radiation incident on a photosensitive surface is given as below.



80. Describe in brief what is observed when moving electrons are allowed to fall on a thin graphite film and the emergent beam falls on a fluorescent screen.

Ans : **Main 2025, 2017**

When moving electrons are allowed to fall on a thin graphite film, then the electrons from the graphite film will be knocked out, after gaining sufficient energy from the collision with the moving electrons and then this beam of emergent electrons falls on the fluorescent screen, due to which visible radiation will be produced from the screen (i.e. fluorescence), helping in identifying that emission of electrons had been started from the thin film.

81. In photoelectric effect, what is meant by the terms

(i) work function?

(ii) stopping potential?

Ans : **Main 2008, 2001**

(i) The minimum energy needed by an electron to come out from a metal surface is known as work function of the metal. It is denoted by ϕ_0 or W_0 and measured in electron volt (eV).

Work function, $W = h\upsilon_0 = \frac{hc}{\lambda_0}$

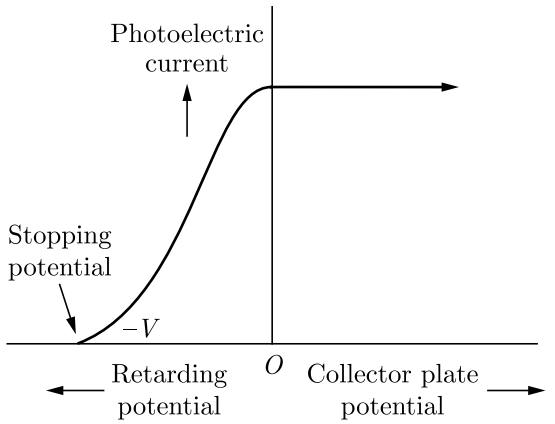
(ii) The minimum negative potential given to anode plate w.r.t. to cathode plate at which the photoelectric current becomes zero is known as stopping potential or cut off potential. It is denoted by V_0. If e is the charge on the photo-electron, then

$$K_{max} = eV_0 = \frac{1}{2}mv_{max}^2$$

Where, m is the mass of photo-electron and V_{max} is the maximum velocity of emitted photoelectrons.

82. Plot a graph showing variation of photoelectric current with collector plate potential at a given frequency and intensity of incident radiation. What does the intercept of the graph with potential axis signify?

Ans : **SQP 2015**



Intercept of the graph with potential axis gives the stopping potential.

83. Show the variation of photo-current with collector plate potential for different frequencies but same intensity of incident radiation.

Ans : **SQP 2012**

The variation of photo-current with collector plate potential for different plate frequencies is shown as below.

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100. Sketch the graphs showing variation of stopping potential with frequency of incident radiations for two photosensitive materials A and B having threshold frequencies $v_A > v_B$.

(i) In which case is the stopping potential more and why?

(ii) Does the slope of the graph depend on the nature of the material used? Explain.

Ans : **SQP 2018**

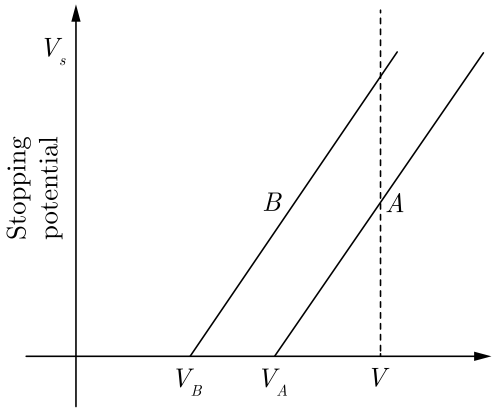
(i) From the graph for the same value of 'ν' stopping potential is more for material 'B'.

From Einsten's photoelectric equation

$$eV_0 = h\nu - h\nu_0$$

$$V_0 = \frac{h}{e}\nu - \frac{h}{e}\nu_0 = \frac{h}{e}(\nu - \nu_0)$$

Hence, V_0 is higher for lower value of ν_0



(ii) No, as slope is given by $\frac{h}{e}$ which is a universal constant.

101. What are photons? State their important properties.

Ans : **Comp 2021, 2018**

According to Plank's quantum theory of radiation, an electromagnetic wave travels in the form of discrete packets of energy called quanta. One quantum of light radiation is called a photon.

The main features of photons are as follows:

1. A photon travels with the speed of light.
2. The frequency of a photon does not change as it travels from one medium to another.
3. The speed of a photon changes as it travels through different media due to the change in its wavelength.
4. The rest mass of a photon is zero i.e., a photon cannot exist at rest.
5. Energy of a photon,

$$E = hv = \frac{hc}{\lambda}$$

6. Momentum of a photon,

$$p = mc = \frac{hv}{c} = \frac{h}{\lambda}$$

7 From Einstein's mass-energy relationship, the equivalent mass m of a photon is given by,

$$E = mc^2 = hv \text{ or } m = \frac{hv}{c^2}$$

102. A proton and an alpha particle are accelerated through the same potential. Which one of the two has

(i) greater value of de-Broglie wavelength associated with it and

(ii) less kinetic energy? Give reason to justify your answer.

Ans : **Main 2011**

(i) de-Broglie wavelength,

Since, $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mqV}}$

For same V,

$$\lambda \propto \frac{1}{\sqrt{mq}}$$

Hence, $\frac{\lambda_p}{\lambda_a} = \sqrt{\frac{m_a q_a}{m_p q_p}}$

$$= \sqrt{\frac{4m_p}{m_p}.\frac{2e}{e}}$$

$$= \sqrt{8} = 2\sqrt{2}$$

Clearly, $\lambda_p > \lambda_a$

Hence, proton has a greater de-Broglie wavelength.

(ii) Kinetic energy,

$$E_K = qV$$

For same V,

$$E_K \propto q$$

$$\frac{E_{K_p}}{E_{K_a}} = \frac{q_p}{q_a}$$

$$= \frac{e}{2e} = \frac{1}{2}$$

Clearly, $E_{K_p} < E_{K_a}$

103. A beam of monochromatic radiation is incident on a photosensitive surface. Answer the following questions.

(i) Do the emitted photoelectrons have the same kinetic energy?

(ii) Does the kinetic energy of the emitted electrons depend on the intensity of incident radiation?

(iii) On what factors does the number of emitted photoelectrons depend?

NODIA

96. Show that the de Broglie wavelength of electron of energy E is given by the relation,

$$\lambda = \frac{h}{\sqrt{2mE}}$$

Ans : SQP 2013

Let an electron of charge e having mass m be accelerated from rest through a potential difference v, than.

Gain in kinetic energy of an electron,

$$E = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2E}{m}} \qquad ...(1)$$

The wavelength associated with moving charge is given by,

$$\lambda = \frac{h}{P} = \frac{h}{mv}$$

From equation (1),

$$\lambda = \frac{h}{\sqrt{2mE}}$$

97. Using photon picture of light, show how Einstein's photoelectric equation can be established. Write two features of photoelectric effect which cannot be explained by wave theory.

Ans : Main 2018

According to photon picture of light the photoelectric effect, electron absorbs a quantum of energy $(h\,v)$ of radiation. If this quantum of energy needed for the electron to escape from the metal surface, the electron is emitted with some kinetic energy, the maximum value of which can be given by,

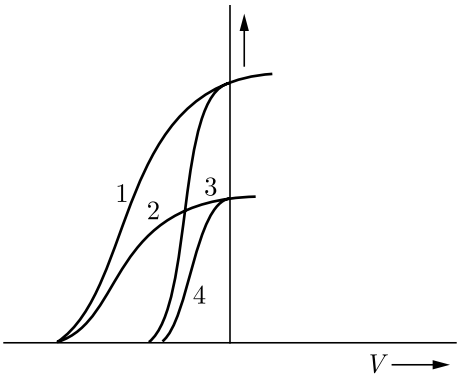
$$K_{\max} = hv - \phi_0$$

This is known as Einstein's photoelectric equation. ϕ_0 is the work function, which is the minimum energy needed by a surface electron to came out.

The two features of photoelectric effect which cannot be explained by wave theory, are

1. Instantaneous emission
2. Existence of threshold frequency.

98. The given graph shows the variation of photoelectric current I versus applied voltage V for two different photosensitive materials and for two different intensities of the incident radiations. Identify the pairs of curves that corresponds to different materials but same intensity of incident radiation.



Ans : SQP 2016

Curves 1 and 2 correspond to similar materials while curves 3 and 4 represent different materials, since the value of stopping potential for the pair of curves (1 and 2) and (3 and 4) are the same. For given frequency of the incident radiation, the stopping potential is independent of its intensity.

So, the pairs of curves (1 and 3) and (2 and 4) correspond to different materials but same intensity of incident radiation.

99. Write three basic properties of photons which are used to obtain Einstein's photoelectric equation. Use this equation to draw a plot of maximum kinetic energy of the electrons emitted versus frequency of incident radiation.

Ans : Comp 2024, 2014

Three basic properties of photons are given as below :

(i) Photons are quanta or discrete carriers of energy.

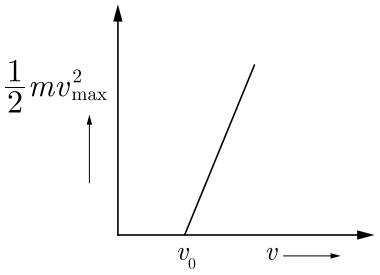
(ii) Energy of a photon is proportional to the frequency of light.

(iii) The photon gives all its energy to the electron with which it interacts.

Einstein's photoelectric equation

$$\frac{1}{2}mv_{\max}^2 = hv - W$$

The plot is shown as below



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(i) According to wave theory, the light propagates in the form of wave-fronts and the energy is distributed uniformly over the wave-fronts. With increase of intensity of light the amplitude of waves and the energy stored by waves will increase. These waves will then, provide more energy to electrons of metal; consequently, the energy of electrons will increase.

Thus, according to wave theory, the kinetic energy of photoelectrons must depend on the intensity of incident light, but according to experimental observations, the kinetic energy of photoelectrons does not depend on the intensity of incident light.

(ii) According to wave theory, the light of any frequency can emit electrons from metallic surface provided the intensity of light be sufficient to provide necessary energy for emission of electrons, but according to experimental observations, the light of frequency less than threshold frequency cannot emit electrons, whatever the intensity of incident light may be.

(iii) According to wave theory, the energy transferred by light waves will not go to a particular electron, but it will be distributed uniformly to all electrons present in the illuminated surface. Therefore, electrons will take some time to collect the necessary energy for their emission. The time for emission will be more for light of less intensity and vice-versa. But experimental observations show that the emission of electrons take place instantaneously after the light is incident on the metal; whatever the intensity of light may be.

FOUR MARKS QUESTIONS

107. Write the basic features of photon picture of electro magnetic radiation on which Einstein's photoelectric equation is based.

Ans : **Main 2014**

Photon picture of electromagnetic radiation on which Einstein's photoelectric equation is based on particle nature of light. Its basic features are given as below.

(a) In interaction of radiation with matter, radiation behaves as if it is made up of particle called photons.

(b) Each photon has energy $E(= hv = \frac{hc}{\lambda})$ and momentum $p(= hv/c = h/\lambda)$, where c is the speed of light, h is Planck's constant, v and λ are frequency and wavelength of radiation.

(c) All photons of light of a particular frequency v or wavelength λ have the same energy $E(= hv = \frac{hc}{\lambda})$ and momentum $p(= \frac{hv}{c} - \frac{h}{\lambda})$ whatever the intensity of radiation may be.

(d) By increasing the intensity of light of given wavelength, there is only an increase in the number of photons per second crossing a given area with each photon having the same energy.

Thus, photon energy is independent of intensity of radiation.

(e) Photon are electrically neutral and are not deflected by electric end magnetic fields.

(f) In a photon particle collision (such as photon-electron collision), the total energy and total momentum are conserved. However, number of photons may not be conserved.

(g) The velocity of photon in different media is different which is due to the change in its wavelength.

NODIA

108. Define the term "cut off frequency" in photoelectric emission. The threshold frequency of a metal is f. When the light of frequency $2f$ is incident on the metal plate, the maximum velocity of photoelectrons is v_1. When the frequency of the incident radiation is increased to $5f$, the maximum velocity of photoelectrons is v_2. Find the ratio of v_1 and v_2.

Ans : **SQP 2008, 2012**

Cut off frequency is that maximum frequency of incident radiation below which no photo-emission takes place from a photoelectric material.

According to Einstein's photoelectric equation

$$E_{K\max} = \frac{hc}{\lambda} - \phi$$

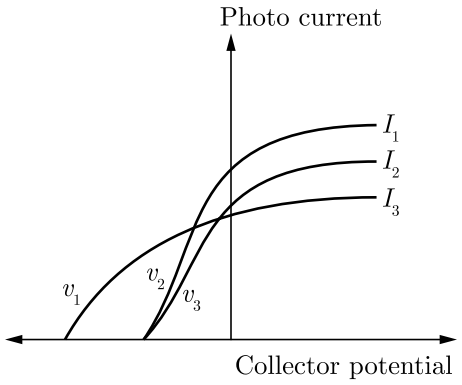
$$= hv - \phi$$

Given that threshold frequency of the metal is f. If light of frequency, $2f$ is incident on metal plane, maximum velocity of photoelectrons is v_1 then,

$$\frac{1}{2}mv_1^2 = h(2f - f)$$

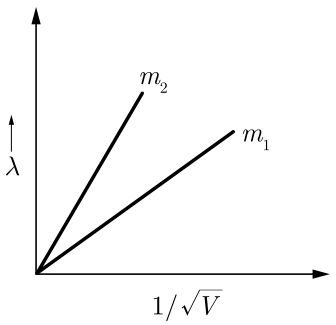
$$\frac{1}{2}mv_1^2 = hf \qquad ...(1)$$

If light of frequency, $5f$ is incident and maximum velocity of photoelectron is v_2.



88. Plot a graph showing variation of de-Broglie wavelength λ versus $\frac{1}{\sqrt{V}}$ where V is accelerating potential for two particles A and B carrying same charge but of masses m_1, m_2 $(m_1 > m_2)$. Which one of the two represents a particle of smaller mass and why?

Ans : **Comp 2017**



As, $$\lambda = \frac{h}{\sqrt{2mqV}}$$

$$\lambda = \left(\frac{h}{\sqrt{2q}} \cdot \frac{1}{\sqrt{m}}\right)\frac{1}{V}$$

$$\frac{\lambda}{\frac{1}{\sqrt{V}}} = \frac{h}{\sqrt{2q}} \cdot \frac{1}{m}$$

As the charge of two particles is same, we get

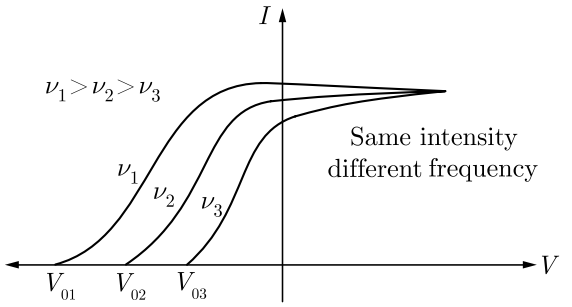
$$\text{Slope} \propto \frac{1}{\sqrt{m}}$$

Hence, particle with lower mass (m_2) will have greater slope.

89. Draw the graphs showing the variations of Photo-electric current with the change in anode potential of a photocell for the following conditions.

1. the same intensity but different frequencies.
2. the same frequency but different intensities.

Ans : **Main 2017**



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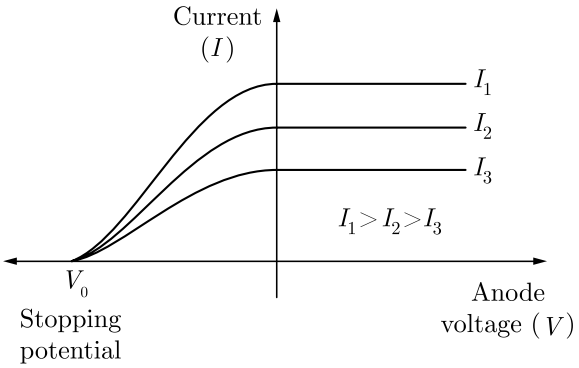

(2)

THREE MARKS QUESTIONS

90. Define threshold frequency, work function and stopping potential with reference to photoelectric effect.

Ans : **Main 2018**

1. **Threshold Frequency :** The minimum value of the frequency of incident radiation below which the photo electric emission stops.
2. **Work Function :** It is the minimum amount of energy required to remove an electron from the surface of given metal.
3. **Stopping Potential :** The value of the retarding potential at which the photoelectric current becomes zero is called cut off or stopping potential.

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$$\frac{1}{\lambda_0} = \frac{2}{\lambda_1} - \frac{1}{\lambda_2}$$

$$\lambda_0 = \frac{\lambda_1\lambda_2}{2\lambda_2 - \lambda_1}$$

$$\text{Work function, } \phi_0 = \frac{hc(2\lambda_2 - \lambda_1)}{\lambda_1\lambda_2}$$

111. Draw a graph showing the variation of stopping potential with the frequency of incident radiation in relation to photoelectric effect.

1. What does the slope of this graph represent?
2. How can the value of Plank's constant be determined from this graph?
3. How can the value of work function of the material be determined from this graph.

Ans : **Comp 2020, 2013**

According to Einstein's photoelectron equation, the maximum kinetic energy. of a photoelectron is given by,

$$K_{max} = h\nu - W_0$$

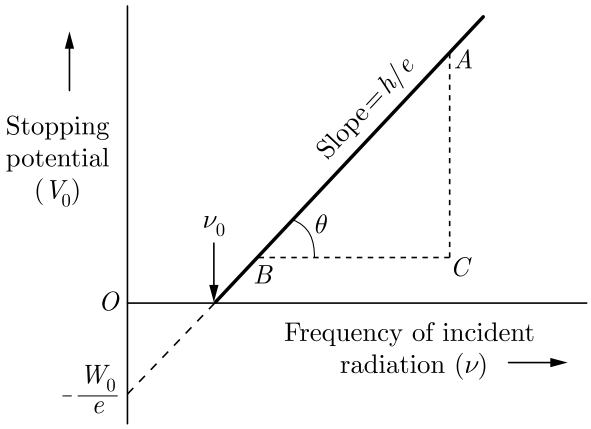
If V_0 is the stopping potential, then

$$K_{max} = eV_0$$

Hence, $$eV_0 = h\nu - W_0$$

or $$V_0 = \left(\frac{h}{e}\right)\nu - \frac{W_0}{e} \quad ...(1)$$

It follows from the above equation that V_0 versus ν graph is a straight line, as shown in figure below.



V_0 Versus ν Graph for a Photosensitive Material

1. Clearly, slope of V_0-ν graph $= \frac{h}{e}$.
2. To determine the slope, take two points A and B on the straight line graph. Then,

$$m = \tan\theta = \frac{AC}{BC} = \frac{h}{e}$$

$$h = e \times \frac{AC}{BC} = e \times \text{slope of } V_0\text{-}\nu \text{ graph}$$

Thus, the Plank's constant h can be determined.

3. Moreover, the intercept on vertical axis $= -\frac{W_0}{e}$
Hence, $W_0 = e \times$ Magnitude of the intercept on vertical axis.
In this way, the work function W_0 can be determined.

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112. State two important properties of photon which are used to write Einstein's photoelectric equation. Define (i) stopping potential and (ii) threshold frequency using Einstein's equation and drawing necessary plot between relevant quantities.

Ans : **Main 2016**

Characteristic properties of photons are as follows:

(a) Energy of photon is directly proportional to the frequency (or inversely proportional to the wavelength).

(b) In photon electron collision, total energy and momentum of the system of two constituents remains constant.

(c) In the interaction of photons with the free electrons, the entire energy of photon is absorbed.
If radiation of frequency (v) greater than threshold frequency (v_0) irradiate the metal surface, electrons emitted out from the metal. So, Einstein's photoelectric equation can be given as

$$E_{K\max} = \frac{1}{2}mv_{\max}^2$$

$$= hv - hv_0$$

(i) Cut off or stopping potential is that minimum value of negative potential at anode which just stops the photoelectric current.

(ii) For a given material, there is a minimum frequency of light below which no photoelectric emission will take place, this frequency is called as threshold frequency.
By Einstein's photoelectric equation

$$E_{K\max} = \frac{hc}{\lambda} - \phi$$

$$= hv - hv_0$$

$$eV_0 = hv - hv_0$$

$$V_0 = \frac{h}{e}v - \frac{h}{e}v_0$$

Clearly, $V_0 - v$ graph is a straight line.

132. Monochromatic light of wavelength 396 nm is incident on the surface of a metal, whose work function is 1.125 eV.

Calculate :

(i) the energy of an incident photon (in eV) .

(ii) the maximum kinetic energy of photoelectrons (in eV).

Ans : **Main 2023**

(i) Given, $\lambda = 396\,\text{nm} = 396 \times 10^{-9}\,\text{m}$

$\phi_0 = 1.125\,\text{eV}$

Energy of incident photon,

$$E = \frac{hc}{\lambda}$$

$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{396 \times 10^{-9}}$$

$$= 0.05 \times 10^{-17} = 5 \times 10^{-19}\,\text{J}$$

$$= 5 \times 10^{-19}/1.6 \times 10^{-19}$$

$$= 3.125\,\text{eV}$$

(ii) $K_{\max} = E - \phi_0 = 3.125 - 1.125$

133. If the work function of aluminium is 4.125 eV, what is the cut off wavelength for photoelectric effect for aluminium is (Take $h = 6.6 \times 10^{-34}$ J-s)

Ans : **Main 2014**

Work function of the aluminium,

$$\phi_0 = 4.125\,\text{eV}$$

$$= 4.125 \times (1.6 \times 10^{-19})$$

$$= 6.6 \times 10^{-19}\,\text{J}$$

and Planck's constant,

$$h = 6.6 \times 10^{-34}\,\text{J-s}$$

Cut off wavelength of aluminium,

$$\lambda_0 = \frac{hc}{\phi_0}$$

$$= \frac{(6.6 \times 10^{-34}) \times (3 \times 10^{8})}{6.6 \times 10^{-19}}$$

$$= 3 \times 10^{-7}\,\text{m}$$

$$= 300 \times 10^{-9}\,\text{m}$$

$$= 300\,\text{nm}$$

Where, $c =$ Velocity of light equal to $3 \times 10^{8}\,\text{m-s}^{-1}$

134. Monochromatic light of wavelength 198 nm is incident on the surface of a metallic cathode whose work function is 25 eV. How much potential difference must be applied between the cathode and the anode of a photocell to just stop the photo-current from flowing?

Ans : **Main 2008**

Wavelength, $\lambda = 198\,\text{nm} = 198 \times 10^{-9}\,\text{m}$

Work function,

$$\phi_0 = 2.5\,\text{eV}$$

$$= 2.5 \times 1.6 \times 10^{-19}$$

$$= 4 \times 10^{-19}\,\text{J}$$

From Einstein's photoelectric equation,

$$eV_0 = \frac{hc}{\lambda} - \phi_0$$

Stopping potential,

$$V_0 = \frac{1}{e}\left(\frac{hc}{\lambda} - \phi_0\right)$$

$$= \frac{1}{1.6 \times 10^{-19}}\left(\frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{198 \times 10^{-9}} - 4 \times 10^{-19}\right)$$

$$= \frac{1}{1.6 \times 10^{-19}}(0.1 \times 10^{-17} - 4 \times 10^{-19})$$

$$V_0 = \frac{6 \times 10^{-19}}{1.6 \times 10^{-19}} = 3.75\,\text{V}$$

135. The mass of a particle moving with velocity 5×10^{6} m/s has de-Broglie wavelength associated with it to be 0.135 nm. Calculate its mass.

Ans : **Comp 2025, 2012**

De-Broglie matter wave equation is given by,

$$\lambda = \frac{h}{p}$$

$$= \frac{h}{\sqrt{2mE_K}} \qquad (\because p = \sqrt{2mE_K})$$

Where,

$m =$ mass of proton

$E_K =$ kinetic energy of proton

Kinetic energy of proton is given by ,

$E_K = m_e c^2$ (Einstein's mass-energy relation)

$$\lambda = \frac{h}{\sqrt{2m(m_e c^2)}}$$

$$\lambda = \frac{h}{\sqrt{2}\, c\sqrt{mm_e}}$$

$$= \frac{h}{\sqrt{2}\, c \times (m_e)\sqrt{1836}} \quad (\because m = 1836 m_e)$$

$$\lambda = \frac{6.63 \times 10^{-34}}{1.414 \times (3 \times 10^{8}) \times 9.1 \times 10^{-31} \times 42.8}$$

136. A proton and an α −particle have the same de-Broglie wavelength. Determine the ratio of (1) their accelerating potentials (2) their speeds.

Ans : **Comp 2018**

De-Broglie wavelength,

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mqV}}$$

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Since, $p = mv$

$$v = \frac{p}{m}$$

$$= \frac{1}{2}m\left(\frac{p}{m}\right)^2$$

$$= \frac{p^2}{2m}$$

$$p = \sqrt{2mE_K}$$

From the equation (1) ,we get

$$\lambda = \frac{h}{\sqrt{2mE_K}} \quad ...(2)$$

If V volt is accelerating potential of electron, then kinetic energy

$$E_K = eV$$

Equation (2) gives

$$\lambda = \frac{h}{\sqrt{2meV}} \quad ...(3)$$

Substituting the given volume, we get

$m = 9.1 \times 10^{-31}$ kg,

$e = 1.6 \times 10^{-19}$ C,

$h = 6.63 \times 10^{-34}$ Js, we get

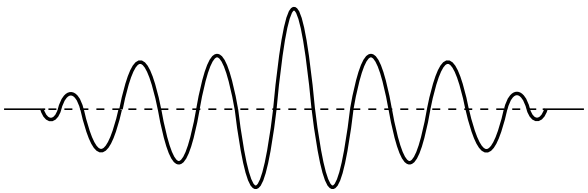
$$\lambda = \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19}\,\text{V}}}$$

$$= \frac{12.27}{\sqrt{V}} \times 10^{-10}\text{m}$$

$$\lambda = \frac{12.27}{\sqrt{V}}\text{Å}$$

This is the required expression for de-Broglie wavelength associated with electron accelerated to potential of V volt.

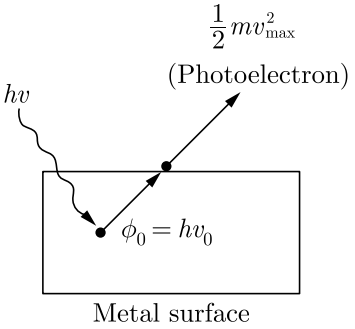
The diagram of wave packet describing the motion of a moving electron is shown.



115. Write down Einstein's photoelectric equation and explain the photoelectric effect on its basis.

Ans : **Main 2025, 2018**

When a quantum of light radiation of energy hv falls on a metal surface, then this energy is absorbed by the electron and is used in following two ways:



1. A part of energy is used to overcome the surface barrier and come out of the metal surface. This part of energy is called work function. It is expressed as $\phi_0 = hv_0$.
2. The remaining part of the energy is used in giving a velocity v to the emitted photoelectrons. This is equal to the maximum kinetic energy of the photoelectrons. $(\frac{1}{2}mv^2_{max})$, where m is the mass of the photoelectrons.

   According to the law of conservation of energy,we can write the

$$hv = \phi_0 + \frac{1}{2}mv^2_{max}$$

$$= hv_0 + \frac{1}{2}mv^2_{max}$$

Hence, $\frac{1}{2}mv^2_{max} = K_{max}$

$$= h(v - v_0)$$

$$= hv - \phi_0$$

Hence, $K_{max} = hv - \phi_0$

This equation is called Einstein's photoelectric equation.

Verification of Laws of Photoelectric Emission Based on Einstein's Photoelectric Equation

Einstein's photoelectric equation is,

$$K_{max} = \frac{1}{2}mv^2_{max} = h(v - v_0)$$

This equation successfully explain the laws of photoelectric emission. These are as follows:

1. If $v < v_0$, then $\frac{1}{2}mv^2_{max}$ is negative which is not possible therefore, for photoelectric emission to take place $v > v_0$.
2. Since, one photon emits one electron, so the number of photoelectrons emitted per second is directly proportional to the intensity of incident light.
3. It is clear that $\frac{1}{2}mv^2_{max} \propto v$, as h and v_0 are constants. This shows that kinetic energy of the photoelectrons is directly proportional to the frequency of the incident light.

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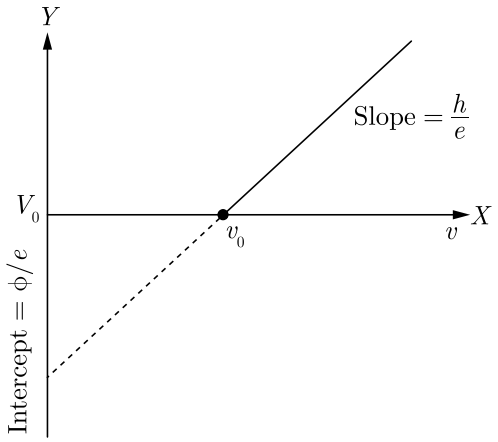

113. What is photoelectric emission effect? What are the laws of photoelectric emission effect? How did Einstein explain these laws of photoelectric effect?

Ans : SQP 2016, 2014

Photoelectric emission is the process in which electrons are emitted from a metal surface when electromagnetic radiations of sufficiently high frequency are incident on it. The emitted electrons are called photoelectrons but their rate of emission is very low.

Laws of Photoelectric Emission : On the basis of the experimental results on photoelectric effect, Lenard and Millikan gave the following laws of photoelectric emission.

1. For a given photosensitive material and frequency of incident radiation, (above the threshold frequency), the photoelectric current is directly proportional to the intensity of light. The saturation current is directly proportional to the intensity of incident radiation.
2. For a given photosensitive material, there exists a certain minimum cut-off frequency below which no photoelectrons are emitted, howsoever high is the intensity of incident radiation. This frequency is called threshold frequency.
3. Above the threshold frequency, the stopping potential or equivalently the maximum kinetic energy of the photoelectrons is directly proportional to the of incident radiation, but is independent of its intensity.
4. The photoelectric emission is an instantaneous process. The time lag between the incidence of light radiation and the emission of photoelectrons is very small, even less than 10^{-9} s.

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Explanation of Law of Photoelectric Emission

1. **Explanation of Effect of Intensity :** The increase of intensity mean the increase in the number of photons striking the metal surface per unit time. As each photon ejects only one electron, so the number of ejected photoelectrons increases with the increases in intensity of incident radiation.
2. **Explanation of Threshold Frequency :** If $\nu < \nu_0$ i.e., the frequency of incident radiation is less than the threshold frequency, the kinetic energy of photo electrons becomes negative. This has no physical meaning. So photoelectric emission does not occur below the threshold frequency.
3. **Explanation of Kinetic Energy :** If $v > v_0$, then

$$K_{\max} = \frac{1}{2} m v^2_{\max} \propto \nu$$

i.e., above the threshold frequency, the maximum kinetic energy of the electrons increases linearly with the frequency ν of the incident radiation. Moreover, the increase in intensity increases only the number of incident photons and not their energy. Hence the maximum kinetic energy of the photoelectrons is independent of the intensity radiation.

4. **Explanation of Time Lag :** Photoelectric emission is the result of an elastic collision between a photon and an electron. Thus the absorption of energy from a photon by a free electron inside the metal is a single event which involves transfer of energy in one lump instead of the continuous absorption of energy as in the wave theory of light. Hence there is no time lag between the incidence of photon and the emission of a photoelectrons.

114. Deduce de-Broglie wavelength of electrons accelerated by a potential of V volt. Draw a schematic diagram of a localized wave describing the wave nature of moving electron.

Ans : SQP 2017, 2015

The de-Broglie wavelength associated with electrons of momentum p is given by

$$\lambda = \frac{h}{p} = \frac{h}{mv} \qquad ...(1)$$

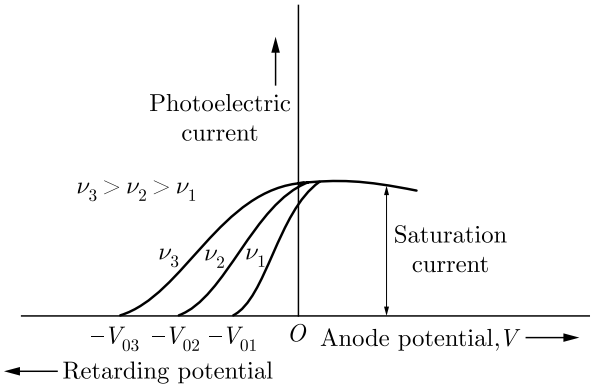
Where m is mass and v is velocity of electron. If E_K is the kinetic energy of electron, then

$$E_K = \frac{1}{2} m v^2$$

frequency of incident radiation, the stopping potential is independent of its intensity.

3. **Effect of Frequency of Incident Radiation on Stopping Potential :** To study the effect of frequency on photoelectric effect, the intensity of incident radiation at each frequency is adjusted in such a way that the saturation current is same each time when the plate A is at a positive potential. The potential on the plate A is gradually reduced to zero and then increased in the negative direction till stopping potential is reached. The experiment is repeated with radiations of different frequencies.

   As shown in Figure, the value of stopping potential increases with the frequency of incident radiation. For frequencies $\nu_3 > \nu_2 > \nu_1$, the corresponding stopping potentials vary in the order $V_{03} > V_{02} > V_{01}$.



Variation of Photoelectric Current with Anode Potential for Different Frequencies of Incident Radiation

If we plot a graph between the frequency of incident radiation and the corresponding stopping potential for different metals, we get straight line graphs, as shown in Figure. These graphs reveal the following facts :

(a) The stopping potential or the maximum kinetic energy of the photoelectrons increases linearly with the frequency of the incident radiation, but is independent of its intensity.

(b) There exists a certain minimum cut-off frequency for which the stopping potential is zero. The minimum value of the frequency of incident radiation below which the photoelectric emission stops altogether is called threshold frequency.

(c) For two different metals A and B, these graphs have same slope. But the threshold frequencies are different.

NUMERICAL QUESTIONS

117. Calculate the momentum of a photon of energy 6×10^{-19} J.

Ans : **Main 2017**

Given $E = 6 \times 10^{-19}$ J

Momentum, $p = \dfrac{E}{c}$

Where, c is speed of light.

$$= \frac{6 \times 10^{-19}}{3 \times 10^{8}} = 2 \times 10^{-27} \text{ J/ms}^{-1}$$

118. What is the momentum (p) of photon from ultraviolet light of wavelength $\lambda = 332$ nm ?

Ans : **Main 2005**

Wavelength, $\lambda = 332 \text{ nm} = 332 \times 10^{-9}$ m

So, from de-Broglie relation,

$$\lambda = \frac{h}{p}$$

$$p = \frac{h}{\lambda} = \frac{6.6 \times 10^{-34} \text{ J} - \text{s}}{332 \times 10^{-9} \text{ m}}$$

$$\approx 2 \times 10^{-27} \text{ kg ms}^{-1}$$

119. Find the momentum of a photon of energy 3.0 eV.

Ans : **Main 2009**

Photon of energy $= 3.0 \text{ eV} = 3 \times 1.6 \times 10^{-19}$ J

$$\text{Momentum, } p = \frac{\text{Energy}}{c(\text{Velocity of light})}$$

$$= \frac{3 \times 1.6 \times 10^{-19} \text{ J}}{3 \times 10^{8} \text{ m/s}}$$

$$= 1.6 \times 10^{-27} \text{ kg ms}^{-1}$$

120. Threshold frequency of a certain metal for photoelectric emission is 5×10^{14} Hz. Calculate its work function.

Ans : **Main 2012, 2009**

Threshold frequency,

$$v_0 = 5 \times 10^{14} \text{ Hz}$$

So, work function is given by, $\phi = hv_0$

$$\phi = 6.6 \times 10^{-34} \times 5 \times 10^{14}$$

$$\phi = 3.3 \times 10^{-19} \text{ J}$$

$$\phi = \frac{3.3 \times 10^{-19}}{1.6 \times 10^{-19}} = 2.06 \text{ eV}$$

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121. Calculate the momentum of photon of green light of $\lambda = 500\,\text{nm}$ in SI unit.

Ans : **Main 2007, 2015**

Given,

Wavelength, $\lambda = 500\,\text{nm} = 500 \times 10^{-9}\,\text{m}$

According to de-Broglie relation,

$$\lambda = \frac{h}{p} \quad [\text{Where, } p = \text{momentum}]$$

$$p = \frac{h}{\lambda}$$

$$= \frac{6.6 \times 10^{-34}\,\text{J} - \text{s}}{500 \times 10^{-9}\,\text{m}}$$

$$= 1.32 \times 10^{-27}\,\text{kg ms}^{-1}$$

122. Find the de-Broglie wavelength of electrons moving with a speed of $7 \times 10^6\,\text{ms}^{-1}$.

Ans : **Main 2017**

Speed, $v = 7 \times 10^6\,\text{m/s}$

De-Broglie wavelength is given as,

$$\lambda = \frac{h}{p} = \frac{h}{m_e v}$$

Where, m_e = mass of the electron,

$$\lambda = \frac{6.6 \times 10^{-34}}{9 \times 10^{-31} \times 7 \times 10^6}$$

$$= 1.0476 \times 10^{-10}\,\text{m}$$

$$= 10.476\,\text{Å}$$

123. If the wavelength of a photon is 4000 Å. What is the energy of photon? ($c = 3 \times 10^8\,\text{m-s}^{-1}$)

Ans : **SQP 2025, 2019**

Wavelength of photon,

$$\lambda = 4000\,\text{Å}$$

$$= 4000 \times 10^{-10}\,\text{m}$$

Velocity of light, $c = 3 \times 10^8\,\text{m-s}^{-1}$

Energy of a photon, $E = \frac{hc}{\lambda}$

where, h = Plank's constant equal to 6.6×10^{-34} J-s

$$= \frac{(6.6 \times 10^{-34}) \times (3 \times 10^8)}{(4000 \times 10^{-10})}$$

$$= 4.95 \times 10^{-19}\,\text{J}$$

124. Calculate the de-Broglie wavelength of the electron orbiting in the $n = 2$ state of hydrogen atom.

Ans : **Main 2020, 2016**

Kinetic energy for the second state,

$$E_K = \frac{13.6\,\text{eV}}{4} = \frac{13.6\,\text{eV}}{2^2}$$

$$= \frac{13.6\,\text{eV}}{4}$$

$$= 3.4 \times 1.6 \times 10^{-19}\,\text{J}$$

De-Broglie wavelength,

$$\lambda = \frac{h}{\sqrt{2mE_K}}$$

$$= \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 3.4 \times 1.6 \times 10^{-19}}}$$

$$= 0.67\,\text{nm}$$

$$K_{\max} = 2\,\text{eV}$$

125. What is the velocity of an electron having de-Broglie's wavelength of 10^{-10}m? (Take $h = 6.6 \times 10^{-34}$ J-s)

Ans : **SQP 2011**

De-Broglie's wavelength of electron,

$$\lambda = 10^{-10}\,\text{m}$$

Planck's constant $h = 6.6 \times 10^{-34}$ J-s

Velocity of electron, $v = \frac{h}{m\lambda}$

$$= \frac{6.6 \times 10^{-34}}{(9.1 \times 10^{-31})(10^{-10})}$$

Where, m = Mass of electron to 9.1×10^{-31} kg)

$$= 7.25 \times 10^6\,\text{m-s}^{-1}$$

126. Threshold wavelength for a certain metal for photoelectric effect is 600 nm.

Calculate its

(i) threshold frequency

(ii) work function

Ans : **Main 2022 Sem-II**

Threshold wavelength,

$$\lambda = 600\,\text{nm} = 600 \times 10^{-9}\,\text{m}$$

(i) Threshold frequency,

$$v_0 = \frac{c}{\lambda_0}$$

$$= \frac{3 \times 10^8}{600 \times 10^{-9}} = 5 \times 10^{14}\,\text{Hz}$$

(ii) Work function,

$$\phi = hv_0 = 6.63 \times 10^{-34} \times 5 \times 10^{14}$$

$$= 33.15 \times 10^{-20}\,\text{J}$$

127. The work function of sodium is 2.28 eV.

(i) What is the minimum energy for a quantum of radiation to cause photoelectric emission from sodium surface?

(ii) Calculate the wavelength of this radiation.

NODIA

Ans : **Main 2009**

(i)

Work function, $\phi_0 = 2.28\,\text{eV}$

So, minimum energy for photo-current

$$\phi_0 = 2.28 \times 1.6 \times 10^{-19}$$
$$= 3.648 \times 10^{-19}\,\text{J}$$

(ii) As we know that,

$$E = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{E} = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{3.648 \times 10^{-19}\,\text{J}}$$
$$= 5.428 \times 10^{-7}\,\text{m}$$
$$= 5428\,\text{Å}$$

128. If threshold wavelength for photoelectric effect on sodium is 5000Å, What is the work function of sodium? (Take $h = 6.6 \times 10^{-34}$ J-s)

Ans : **Comp 2024, 2017**

Threshold wavelength of sodium,

$$\lambda_0 = 5000\,\text{Å}$$
$$= 5000 \times 10^{-10}\,\text{m}$$

and Planck's constant,

$$h = 6.6 \times 10^{-34}\,\text{J-s}$$

Work function of sodium,

$$\phi_0 = \frac{hc}{\lambda_0}$$
$$= \frac{(6.6 \times 10^{-34}) \times (3 \times 10^{8})}{500 \times 10^{-10}}$$

(Where, c = Velocity of light equal to $3 \times 10^{8}\,\text{m-s}^{-1}$)

$$= 3.96 \times 10^{-19}\,\text{J}$$
$$= \frac{3.96 \times 10^{-19}}{1.6 \times 10^{-19}} = 2.5\,\text{eV}$$

129. A monochromatic source of light emits light of wavelength 198 nm.

Calculate

(i) the energy of each photon

(ii) the momentum of photon.

Ans : **Main 2011**

(i) wavelength

$$\lambda = 198\,\text{nm} = 198 \times 10^{-9}\,\text{m}$$

Energy of photon,

$$E = \frac{hc}{\lambda}$$
$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{198 \times 10^{-9}}$$
$$= 10^{-18}\,\text{J}$$

(ii) As wavelength of photon is given by

$$\lambda = \frac{h}{p} \Rightarrow p = \frac{h}{\lambda} = \frac{6.6 \times 10^{-34}\,\text{J-s}}{198 \times 10^{-9}\,\text{m}}$$
$$= 3.33 \times 10^{-27}\,\text{kg ms}^{-1}$$

130. Electrons initially at rest, are passed through a potential difference of 2 kV. Calculate their

(i) final velocity.

(ii) de-Broglie wavelength.

Ans : **Main 2009, 2005**

(i) Potential difference,

$$V = 2\,\text{kV} = 2000\,\text{Volt}$$

and,

$$eV = \frac{1}{2}mv^2$$

So, $$v^2 = \frac{2eV}{m} \Rightarrow v = \sqrt{\frac{2eV}{m}}$$

$$= \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 2000}{9.1 \times 10^{-31}}}$$
$$= \sqrt{\frac{6.4}{9.1} \times 10^{15}} = 2.65 \times 10^{7}\,\text{m/s}$$

(ii) Now, de-Broglie wavelength for electrons is given by

$$\lambda = \frac{12.27}{\sqrt{V}}\,\text{Å} = \frac{12.27}{\sqrt{2 \times 10^{3}}} = 0.274\,\text{Å}$$

131. De-Broglie wavelength of electrons of kinetic energy E is λ. What will he its value, if kinetic energy of electrons made $4E$?

Ans : **Main 2010**

As from de-Broglie relation,

$$\lambda = h/p$$

We know that, $$\text{KE} = \frac{p^2}{2m}$$

$$p = \sqrt{2m\,\text{KE}}$$

Now, $$\lambda = \frac{h}{\sqrt{2m\,\text{KE}}} \quad \ldots(1)$$

According to the question,

New kinetic energy $= 4\,\text{KE}$

New, wavelength, $\lambda' = \frac{h}{\sqrt{2m \times 4\,\text{KE}}}$

$$\lambda' = \frac{1}{2}\left(\frac{h}{\sqrt{2m\,\text{KE}}}\right) \quad \ldots(2)$$

From Eqs. (1) and (2), we get

$$\lambda' = \frac{1}{2} \times \lambda \Rightarrow \lambda' = \frac{\lambda}{2}$$

So, new wavelength is the half of the first wavelength when kinetic energy of electrons made $4E$.

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4. Photoelectric emission is due to elastic collisions between a photon and an electron. As such there cannot be any significant time lag between the incidence of photon and emission of photoelectrons.

116. Describe an experimental arrangement to study photoelectric effect. Explain the effect of:

1. Intensity of light on photoelectric current
2. Potential on photoelectric current
3. Frequency of incident radiation on shopping potential.

Ans : **SQP 2021**

Figure shows the experimental arrangement used for the study of photoelectric effect. It consists of an evacuated glass/quartz tube which encloses a photosensitive plate C and another metal plate A. The two electrodes are connected to a high tension battery, a potential divider arrangement and a micro ammeter μA. When monochromatic radiations of a sufficiently high frequency fall on the plate C, electrons are emitted which are collected by the plate A. So a current, called photoelectric current, flows in the outer circuit which is measured by the micrometer μA.

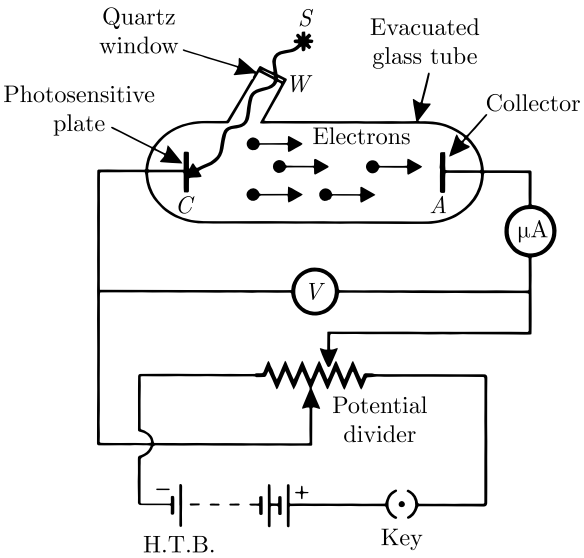
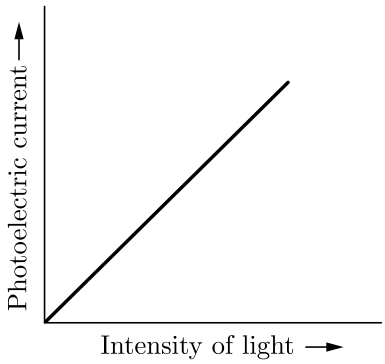


Figure : Experimental Arrangement to Study Photoelectric Effect

1. **Intensity of Light on Photoelectric Current :** If we allow radiations of a fixed frequency to fall on plate P and the accelerating potential difference between the two electrodes is kept fixed, then the photoelectric current is found to increase linearly with the intensity of incident radiation, as shown in Figure. Since the photoelectric current is directly proportional to the number of photoelectric emitted per second, this implies that the number of photoelectrons emitted per second is proportional to the intensity of incident radiation.



2. **Effect of Potential :** As shown in Figure, if we keep the intensity I_1 and the frequency of incident radiation fixed, and increase the positive potential (called accelerating potential) on plate A gradually, it is found that the photoelectric current increases with the increase in accelerating potential till a stage is reached when the photoelectric current becomes maximum and does not increase further with the increase in the accelerating potential. This maximum value of the photoelectric current is called the saturation current. At this stage, all the electrons emitted by the plate C are collected by the plate A.

Now, if we apply a negative potential on plate A with respect to plate C and increase its magnitude gradually, it is seen that the photoelectric current decreases rapidly until it becomes zero for a certain value of negative potential on plate A. The value of the retarding potential at which the photoelectric current becomes zero is called cut off or stopping potential for the given frequency of the incident radiation. At the stopping potential V_0, when no photoelectrons are emitted, the work done by stopping potential on the fastest electron must be equal to its kinetic energy. Hence,

$$K_{\max} = \frac{1}{2} m v_{\max}^2 = e V_0$$

If we repeat the experiment with incident radiation of the same frequency but of higher intensity I_2 and I_3 $(I_3 > I_2 > I_1)$, we find that the values of saturation currents have increased in proportion to the intensity of incident radiation, while the stopping potential is still the same. Thus, for a given

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Where, $m =$ mass of charge particle

$q =$ charge of particle

$V =$ potential difference

(1) $\lambda^2 = \dfrac{h^2}{2mqV}$

$V = \dfrac{h^2}{2mq\lambda^2}$

Hence, $\dfrac{V_p}{V_\alpha} = \dfrac{2m_\alpha q_\alpha}{2m_p q_p} = \dfrac{2 \times 4m2q}{2mq} = \dfrac{8}{1}$

$V_p : V_\alpha = 8:1$

(2) $\lambda = \dfrac{h}{mv},\ \lambda_p = \dfrac{h}{m_p v_p},\ \lambda_a = \dfrac{h}{m_\alpha v_\alpha}$

$\lambda_p = \lambda_\alpha$

$\dfrac{h}{m_p v_p} = \dfrac{h}{m_\alpha v_\alpha}$

$\dfrac{v_p}{v_\alpha} = \dfrac{m_a}{m_p} = \dfrac{4}{1} = 4:1$

137. An electron and a proton, each have de-Broglie wavelength of 1.00 nm.

1. Find the ratio of their momenta.
2. Compare the kinetic energy of the proton with that of the electron.

Ans : **Main 2015**

1. $\lambda_e = \dfrac{h}{p_e}$

and $\lambda_p = \dfrac{h}{p_p},\ \lambda_e = \lambda_p = 1.00\,\text{nm}$

So, $\dfrac{\lambda_e}{\lambda_p} = \dfrac{p_p}{p_e} = \dfrac{1}{1}$

$\dfrac{p_p}{p_e} = \dfrac{1}{1} = 1:1$

2. From relation,

$E_k = \dfrac{1}{2}mv^2 = \dfrac{p^2}{2m}$

$E_{Ke} = \dfrac{p_e^2}{2m_e}$

and $K_p = \dfrac{p_p^2}{2m_p}$

$\dfrac{E_{kp}}{E_{ke}} = \dfrac{p_p^2}{2m_p} \times \dfrac{2m_e}{P_e^2} = \dfrac{m_e}{m_p}$

Since, $m_e << m_p$.

So, $E_{Kp} << E_{Ke}$

$\dfrac{E_{Kp}}{E_{Ke}} = \dfrac{9.1 \times 10^{-31}}{1.67 \times 10^{-27}} = 5.4 \times 10^{-4}$

138. Threshold wavelength of certain metal is 792 nm. What is the maximum kinetic energy of photoelectrons emitted by this metal, if it is exposed to ultraviolet light of wavelength 396 nm?

Ans : **Main 2010**

Threshold wavelength,

$\lambda_0 = 792\,\text{nm} = 792 \times 10^{-9}\,\text{m},$

Incident wavelength,

$\lambda = 396\,\text{nm}$

$= 396 \times 10^{-9}\,\text{m}$

So, By Einstein's photoelectric equation,

Maximum kinetic energy

$KE_{\max} = hv - \phi_0$

So, $KE_{\max} = \dfrac{hc}{\lambda} - \dfrac{hc}{\lambda_0}$

$[\phi_0 =$ work function, $hv =$ energy$]$

$= hc\left[\dfrac{1}{\lambda} - \dfrac{1}{\lambda_0}\right]$ $[\text{asv} = c/\lambda]$

$= 6.6 \times 10^{-34} \times 3 \times 10^8 \left[\dfrac{1}{396 \times 10^{-9}} - \dfrac{1}{792 \times 10^{-9}}\right]$

$= 25 \times 10^{-20}\,\text{J}$

139. A light of wavelength 6000 Å is incident on a metal of work function 2 eV. Will electrons be emitted? If yes, find maximum energy of emitted electron.

Ans : **Comp 2021, 2002**

Wavelength of light,

$\lambda = 6000\mathring{A} = 6000 \times 10^{-10}\text{m}$

Work function, $\phi = 2\,\text{eV}$

Energy of photon, $E = h\nu = h\dfrac{c}{\lambda}$ $\left[\text{Since}, \nu = \dfrac{c}{\lambda}\right]$

$= \dfrac{6.62 \times 10^{-34} \times 3 \times 10^8}{6000 \times 10^{-10}\text{m}}$

$= 3.31 \times 10^{-19}\text{J}$

$= \dfrac{3.31 \times 10^{-19}}{1.6 \times 10^{-19}} = 2.07\,\text{eV}$

As $E > \phi$, so electron will be emitted.

According to Einstein's photoelectric emission, we have

$KE_{\max} = E - \phi$

$= 2.07 - 2.0 = 0.07\,\text{eV}$

De-broglie wavelength of the emitted electron,

$\lambda_{e\min} = \dfrac{12.27}{\sqrt{KE_{\max}(\text{eV})}}$

$= \dfrac{12.27}{\sqrt{0.07}} = 46.37\mathring{A}$

$\lambda > \lambda_{e\min}$

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140. If the frequency of the incident radiation is increased from 4×10^{15} Hz to 8×10^{15} Hz, by how much will the stopping potential for a given photosensitive surface go up?

Ans : **Main 2014, 2017**

According to Einstein's photoelectric equation,

$$KE_{\max} = hv - \phi$$

where, $hv =$ Energy of incident photon,

$\phi =$ work function.

Now for 1st case,

$$KE_1 = h \times 4 \times 10^{15} - hv_0 \qquad [\phi = hv_0]$$

For 2nd case,

$$KE_2 = h \times 8 \times 10^{15} - hv_0$$

Change in $KE = KE_2 - KE_1$

$$= h(8 \times 10^{15} - 4 \times 10^{15})$$

$$= h \times 4 \times 10^{15}$$

As, $KE_1 = eV_1$ and $KE_2 = eV_2$

So, $eV_2 - eV_1 = h \times 4 \times 10^5$

$$(V_2 - V_1) = \frac{h}{e} \times 4 \times 10^{15}$$

$$(V_2 - V_1) = \frac{6.63 \times 10^{-34} \times 4 \times 10^{15}}{1.6 \times 10^{-19}}$$

$$= 16.5 \text{ V}$$

141. The kinetic energy of the fastest moving photoelectron from a metal of work function 2.8 eV is 2 eV. If the frequency of light is doubled, What is the kinetic energy of photoelectron?

Ans : **SQP 2013**

Work function of metal,

$$\phi_0 = 2.8 \text{ eV}$$

Initial maximum kinetic energy of photoelectrons,

$$E_{\max_1} = 2 \text{ eV}$$

Initial frequency of light,

$$\nu_1 = \nu$$

and Final frequency of light,

$$\nu_2 = 2\nu$$

Initial kinetic energy of photoelectrons,

$$E_{\max_1} = h\nu_1 - \phi_0$$

or $$h\nu_1 = K_{\max_1} + \phi_0$$

$$= 2 + 2.8 = 4.8 \text{ eV}$$

Similarly, final kinetic energy of photoelectrons,

$$E_{\max_2} = h\nu_2 - \phi_0$$

$$= h(2\nu_1) - \phi_0$$

$$= 2h\nu_1 - \phi_0$$

$$= (2 \times 4.8) - 2.8$$

$$= 9.6 - 2.8 = 6.8 \text{ eV}$$

142. If work function of a metal surface is 2.14 eV, then evaluate

1. The threshold frequency of metal
2. The wavelength of incident light, if the electron emitted with maximum kinetic energy is stopped with reverse voltage of 0.60 V.

Ans : **SQP 2020**

1. Work function of metal surface,

$$\phi_0 = 2.14 \text{ eV}$$

$$= 2.14 \times 1.6 \times 10^{-19} \text{ J}$$

$$\phi = hv_0$$

$$v_0 = \frac{\phi}{h}$$

$$= \frac{2.14 \times 1.6 \times 10^{-19}}{6.62 \times 10^{-34}}$$

$$= 5.17 \times 10^{-14} \text{ Hz}$$

Thus, for frequencies less than this threshold frequency no photoelectrons are rejected.

2. According to the Einstein's photo-electric equation,

$$eV_0 = hv - \phi_0$$

$$eV_0 = \frac{hc}{\lambda} - \phi_0 \qquad \left[\text{Since, } \nu = \frac{c}{\lambda}\right]$$

$$\frac{hc}{\lambda} = eV_0 + \phi_0$$

$$\lambda = \frac{hc}{eV_0 + \phi_0}$$

$$= \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{(0.60 \text{ eV} + 2.14 \text{ eV})}$$

$$= \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{2.74 \times 1.6 \times 10^{-19}}$$

$$= 4.53 \times 10^{-7} \text{m} = 453 \text{ nm}$$

143. Light of two different frequencies, whose photons have energies of 1 eV and 2.5 eV successively illuminate a metal whose work function is 0.5 eV. What is the ratio of maximum velocities of the emitted electrons?

Ans : **Main 2016**

Energy of first photon,

$$E_1 = 1 \text{ eV}$$

Energy of second photon,

$$E_2 = 2.5 \text{ eV}$$

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and work function of the metal,

$$\phi_0 = 0.5\,\text{eV}$$

Maximum kinetic energy of an electron,

$$K_{\max} = \frac{1}{2} m v_{\max}^2$$

We also know that maximum kinetic energy of the emitted electron,

$$\frac{1}{2} m v_{\max}^2 = E - \phi_0$$

or $$v_{\max} = \sqrt{\frac{2(E-\phi_0)}{m}} \propto \sqrt{(E-\phi_0)}$$

Therefore, $$\frac{v_{\max_1}}{v_{\max_2}} = \sqrt{\frac{E_1-\phi_0}{E_2-\phi_0}}$$

$$= \sqrt{\frac{1-0.5}{2.5-0.5}}$$

$$= \sqrt{\frac{0.5}{2}}$$

$$= \sqrt{\frac{1}{4}} = \frac{1}{2}$$

or $$v_{\max_1} : v_{\max_2} = 1:2$$

144. The threshold wavelength of tungsten is 2400 Å when tungsten is illuminated with light of wavelength 1600 Å. Find

(i) work function

(ii) maximum KE of emitted electron

(iii) stopping potential.

Ans : **Main 2005, 2007**

Threshold wavelength,

$$\lambda_0 = 2400\,\text{Å} = 2400 \times 10^{-10}\,\text{m}$$

Wavelength of incident light,

$$\lambda = 1600\,\text{Å} = 1600 \times 10^{-10}\,\text{m}$$

(i) Work function

$$\phi = \frac{hc}{\lambda_0}$$

$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{2400 \times 10^{-10}}$$

$$= 8.25 \times 10^{-19}\,\text{J}$$

$$= 5.16\,\text{eV}$$

(ii) Maximum kinetic energy

$$KE_{\max} = \frac{hc}{\lambda} - \frac{hc}{\lambda_0}$$

[From Einstein photoelectric equation]

$$KE_{\max} = hc\left[\frac{1}{1600 \times 10^{-10}} - \frac{1}{2400 \times 10^{-10}}\right]$$

$$= \frac{hc}{10^{-10}}\left[\frac{2400-1600}{1600 \times 2400}\right]$$

$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^8 \times 800}{10^{-10} \times 1600 \times 2400}$$

$$= 4.125 \times 10^{-19}\,\text{J}$$

$$= 2.578\,\text{eV}$$

(iii) Stopping potential,

$$KE_{\max} = eV_0$$

$$V_0 = \frac{KE_{\max}}{e}$$

$$V_0 = \frac{2.57\,\text{eV}}{e} = 2.57\ \text{volt}$$

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145. Photoelectrons are emitted from a metal surface when UV-light of wavelength $\lambda = 300\,\text{nm}$ is incident on it. The minimum negative potential required to stop the emission of electrons is 0.54 V.

Calculate

(i) the energy of the incident photons.

(ii) the maximum kinetic energy of the photoelectrons emitted.

(iii) the work function of the metal.

Ans : **Main 2003, 2000**

(i) Plank's constant

$$h = 6.6 \times 10^{-34}\,\text{J/s}$$

$$c = 3 \times 10^8\,\text{m/s}$$

Incident wavelength,

$$\lambda = 300\,\text{nm} = 300 \times 10^{-9}\,\text{m},$$

Stopping potential

$$V_0 = 0.54\,\text{V}$$

$$e = 1.6 \times 10^{-19}\,\text{C}$$

Now $$E = \frac{hc}{\lambda}$$

$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{300 \times 10^{-9}}$$

$$= 6.6 \times 10^{-19}\,\text{J}$$

$$= \frac{6.6 \times 10^{-19}}{1.6 \times 10^{-19}} = 4.125\,\text{eV}$$

(ii) Maximum kinetic energy $= eV_0$

$$= 1.6 \times 10^{-19} \times 0.54$$

$$= \frac{1.6 \times 10^{-19} \times 0.54}{1.6 \times 10^{-19}}$$

$$= 0.54\,\text{eV}$$

(iii) Now, work function (ϕ) of metal

= Energy incident – Maximum kinetic energy

$$= 4.125\,\text{eV} - 0.54\,\text{eV}$$

$$= 3.6\,\text{eV}$$

(c) band spectrum

(d) continuous spectrum

Ans : **Main 2012**

When white light passes through sodium vapours, sodium atoms absorb only specific wavelengths corresponding to their characteristic spectral lines (mainly yellow D-lines). The transmitted light therefore shows dark lines on a continuous background. This produces an absorption spectrum.

Thus (a) is correct option.

11. According to the Rutherford's atomic model, the electrons inside the atom

(a) stationary (b) not stationary

(c) centralized (d) none of these

Ans : **SQP 2015**

According to Rutherford's atomic model, electrons revolve around the positively charged nucleus in circular paths. Therefore, electrons are not stationary inside the atom. This motion of electrons around the nucleus was an important feature of Rutherford's model.

Thus (b) is correct option.

12. Nuclear atom model is required to explain the results of

(a) Rydberg's experiment

(b) Rutherford's experiment

(c) Thomson's atom model

(d) Bohr's frequency condition

Ans : **SQP 2012**

In Rutherford's only a very small number of α -particles retrace their path.

Therefore a massive and positive part of an atom should be concentrated in a small portion of the atom. This small positive part having almost entire mass of the atom is called nucleus.

Thus (b) is correct option.

13. The total energy of an electron in the first excited state of hydrogen atom is about $-3.4\,\text{eV}$. Its kinetic energy in this state is

(a) $-3.4\,\text{eV}$ (b) $3.4\,\text{eV}$

(c) $-6.8\,\text{eV}$ (d) $6.8\,\text{eV}$

Ans : **SQP 2024, 2009**

Total energy of electron in first excited state,

$$E = -3.4\,\text{eV}$$

kinetic energy of electron in first excited state,

$$E_K = -E = -(-3.4) = 3.4\,\text{eV}$$

Thus (b) is correct option.

14. The minimum angular momentum of electron in Hydrogen atom will be

(a) $\frac{h}{\pi}$Js (b) $\frac{h}{2\pi}$Js

(c) $h\pi$Js (d) $2\pi h$ Js

Ans : **Main 2018**

According to Bohr's atomic model, the electrons are permitted to circulate only in those orbits in which the angular momentum of an electron is an integral multiple of $\frac{h}{2\pi}$, h being plank's constant.

$$L = \frac{nh}{2\pi}$$

When, $n = 1$

$$L = \frac{h}{2\pi}$$

Hence, the minimum angular momentum of electron in hydrogen atom will be $\frac{h}{2\pi}$.

Thus (b) is correct option.

15. The hydrogen atom can give spectral lines in the Lyman, Balmer and Paschen series. Which of the following statement is correct?

(a) Balmer series is in the visible region.

(b) Paschen series is in the visible region.

(c) Lyman series is in the infra-red region.

(d) Balmer series is in the ultraviolet region.

Ans : **Main 2025**

In Balmer series, all the spectral lines correspond to transition of electrons from higher excited state to the orbit having $n = 2$ i.e., $n_1 = 2$, $n_2 = 3$, 4, 5, ... and maximum wavelength of Balmer series $(n_2 = 3)$, $\lambda_{\max} = 6564\,\text{Å}$ and minimum wavelength of Balmer series $(n_2 = \infty)$, $\lambda_{\min} = 3646\,\text{Å}$. These values of maximum and minimum wavelengths indicate that the series lies in the visible region.

Thus (a) is correct option.

16. The ground state energy of hydrogen atom is $-13.6\,\text{eV}$. What is the potential energy of the electron in this state?

(a) 0 eV (b) 1 eV

(c) 2 eV (d) $-27.2\,\text{eV}$

Ans : **SQP 2013**

Total energy of hydrogen atom in ground state,

$$E = -13.6\,\text{eV}$$

Potential energy of the electron in ground state,

$$P = 2 \times E$$
$$= 2 \times (-13.6) = -27.2\,\text{eV}$$

Thus (d) is correct option.

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(i) Write photoelectric equation given by Einstein

(ii) Define photoelectric current.

Ans :

(i) Photoelectric equation, by Einstein's

$$\frac{1}{2}mv^2 = E_{K\max} = E - \phi$$

Where,

$E_{K\max}$ = maximum kinetic energy of photoelectron,

E = energy of photon incident on the metal surface.

ϕ = work function for the metal.

(ii) Photocurrent is current developed at the time of flow of photoelectrons in the conductor wire.

150. Kamal had knowledge that energy and momentum of an electron are related to frequency and wavelength of the associated matter (de-Broglie) wave by the relations, $E = hv$, $p = \frac{h}{\lambda}$. But when he heard from his friend that value of λ has no physical significances. Kamal requested Ravi to explain such thing clearly. Ravi said to him that according to de-Broglie a particle behaves as a wave, but it is now established that a particle cannot be equivalent to a single wave, but it is equivalent to a group of waves or a wave packet.

As $p = \frac{h}{\lambda}$, so in the discussion of matter waves, a wave packet is significant and hence only wavelength, λ is significant. As a single wave is insignificant, so phase velocity (velocity of a single wave, $V = v\lambda$) is insignificant and thus, frequency v is also insignificant.

Calculate the

(i) momentum and

(ii) de-Broglie wavelength of the electrons accelerated through a potential difference of 56 V.

Ans :

Mass of electron, $m = 9.1 \times 10^{-31}$ kg.

(i) Momentum,

$$p = \sqrt{2mE_K} = \sqrt{2meV}$$

$$= \sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times 56}$$

$$= 4.04 \times 10^{-24} \text{ kg ms}^{-1}$$

(ii) de-Broglie wavelength,

$$= \frac{h}{p}$$

$$= \frac{6.63 \times 10^{-34}}{4.04 \times 10^{24}}$$

$$= 1.64 \times 10^{-10} \text{ m}$$

$$= 0.164 \text{ nm}.$$

151. Light has dual nature. It manifests itself as a wave in diffraction, interference and polarisation, while it shows up particle nature in photoelectric effect, compton scattering, etc. de-Broglie put forward the bold hypothesis that moving particles (like protons, neutrons, electrons, etc.) of matter should display wave like properties under suitable conditions.

His argument was based on the fact that nature was symmetrical and the two physical quantities-matter and energy must have symmetrical character. If radiation shows due aspect so should matter. The waves associated with the moving particles were called matter waves. The de-Broglie wavelength of a particle of mass m moving with velocity v is given by

$\lambda = \frac{h}{p} = \frac{h}{mv}$, where $h =$ Planck's constant

The de-Broglie wavelength is independent of charge and mass of the material particles. It has significant value for sub-atomic particles like electrons, protons, etc., due to their small masses.

(i) What are the matter waves?

(ii) What is relation between de-Broglie wavelength and momentum?

(iii) Is the de-Broglie wavelength dependent on charge?

(iv) Is de-Broglie waves same as electromagnetic wave in nature

Ans :

(i) The waves associated with a moving particle are called matter waves.

(ii) The de-Broglie wavelength of a particle is inversely proportional to the momentum and given by the relation.

$$\lambda = \frac{h}{p}, \text{ where } h = \text{Planck's constant.}$$

(iii) No, de-Broglie wavelength is independent of charge.

(iv) de-Broglie wavelength cannot be electromagnetic wave in nature.

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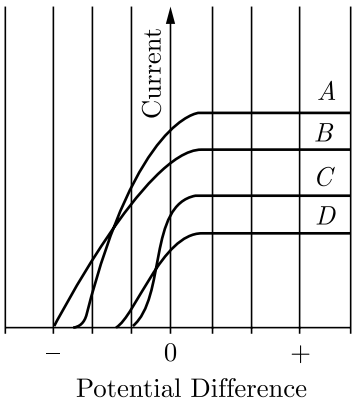
152. (a) Figure shows the variation of photoelectric current measured in a photo cell circuit as a function of the potential difference between the plates of the photo cell when light beams A, B, C and D of different wavelengths are incident on the photo cell. Examine the given figure and answer the following questions :



(i) Which light beam has the highest frequency and why ?

(ii) Which light beam has the longest wavelength and why ?

(iii) Which light beam eject photoelectrons with maximum momentum and why ?

Ans : **Main 2023**

(a) (i) Here B has the highest frequency because higher the frequency of incident light higher the value of stopping potential and *vice-versa*.

(ii) Since, frequency and wavelength are inversely proportional to each other. The wave with the greatest frequency has the shortest wavelength.

So, beam C with lowest frequency have longest wavelength.

(iii) Photon energy and momentum are related by

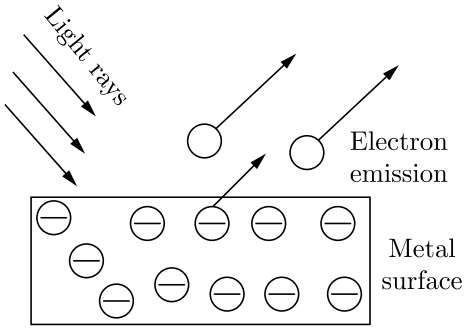
$$p = EC$$

$$p \propto E$$

$$p \propto \frac{1}{\lambda}$$

beam B has the lowest wavelength, then it has the maximum momentum related to it.

153. The phenomenon of emission of electrons from a metal surface, when electromagnetic radiations of sufficiently high frequency are incident on it, is called photoelectric emission. The photo-generated electrons called photoelectrons. The wave theory of EM radiation fails to explain some experimentally, observed facts on photoelectric effect such as its instantaneous nature, independence of the maximum KE of photoelectrons from intensity of incident radiation, and the existence of threshold frequency for every photo-emitter.



According to the photon picture of radiation, in its interaction with matter, the radiation behaves as if it consists of quanta or small packets of energy, each of energy hv. This photon picture leads to the Einstein's photoelectric equations: $K_{\max} = eV_0 = hv - \phi_0$. This equation correctly explains all the experimentally observed features of photoelectric effect.

Answer the following questions from the above passage.

(i) What is photoelectrons?

(ii) What is photon?

(iii) Which equation tells the relation between kinetic energy and work function?

(iv) What is the reason behind failure of wave theory of EM radiation?

Ans :

(i) In photoelectric emission, photo-generated electrons are called photoelectrons.

(ii) Photon is quanta or small packets of energy.

(iii) The Einstein's photoelectric effect equation gives the relation between kinetic energy and work function.

(iv) The wave theory fails to explain the existence of threshold frequency for every photo-emitter.

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CHAPTER 12

Atoms

SUMMARY

1. IMPACT PARAMETER

The perpendicular distance of the velocity vector of α-particle from the central line of the nucleus of the atom is called impact parameter b.

$$b = \frac{1}{4\pi\varepsilon_0}.\frac{Ze^2}{E_K}\cot\frac{\theta}{2}$$

2. DISTANCE OF CLOSEST APPROACH

The smallest distance of approach of α-particle near heavy nucleus is a measure of the size of nucleus. Distance of nearest approach $\approx$ size of nucleus

$$= \frac{1}{4\pi\varepsilon_0}\frac{2Ze^2}{E_K}.$$

where, E_K = kinetic energy of incident α-particle

Z = atomic number

e = electronic charge

3. BOHR'S THEORY OF HYDROGEN ATOM

Bohr combined classical and early quantum concepts and gave his theory in the form of three postulates. These are

1. **Bohr's First Postulate :** It states that an electron in an atom could revolve in certain stable orbits without the emission of radiant energy, contrary to the predictions of electromagnetic theory.
2. **Bohr's Second Postulate :** This postulate states that the electron revolves around the nucleus only in those orbits for which the angular momentum is some integral multiple of $\frac{h}{2\pi}$. Where h is the Planck's constant $(= 6.6 \times 10^{-34}\,\text{J-s})$.Thus, the angular momentum (L) of the orbiting electron is quantised,

i.e., $$L = \frac{nh}{2\pi}$$

As, angular momentum of electron,

$$L = mvr$$

Hence, for any permitted (stationary) orbit,

$$mvr = \frac{nh}{2\pi}$$

where, n = any positive integer i.e., 1, 2, 3,....

It is also called principle quantum number.

3. **Bohr's Third Postulate :** It states that an electron might make a transition from one of its specified non-radiating orbits to another of lower energy. When it does so, a photon is emitted having energy equal to the energy difference between the initial and final states. The frequency of the emitted photon is then given by

$$hv = E_i - E_f$$

where, E_i and E_f are the energies of the initial and final states and $E_i > E_f$.

3.1 Important Terms Related to Bohr's Model

The important terms related to Bohr's model are as follows :

1. Radius of n^{th} orbit is given by

$$r_n = \frac{\varepsilon_0 h^2 n^2}{\pi m Z e^2}$$

For hydrogen atom, $Z = 1$

$$(r_n)_H = \frac{\varepsilon_0 h^2 n^2}{\pi m e^2}$$

The radius of first orbit of hydrogen atom is called Bohr's radius. It is denoted by,

$$a_0 = \frac{\varepsilon_0 h^2}{\pi m e^2} = 0.529 \times 10^{-10}\text{m}$$

$$= 0.529\ \text{Å}$$

2. Energy of Orbiting Electron

Kinetic energy, $E_K = \frac{1}{2}mv^2 = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{2r}$

Potential energy, $U = \frac{1}{4\pi\varepsilon_0}\frac{(Ze)(-e)}{r}$

$$= -\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r}$$

Total energy, $E = -\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{2r}$

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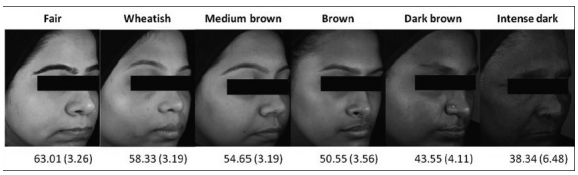
CASE BASED QUESTIONS

146. "Know your face beauty through complexion meter" was one of the stall on a science exhibition. A student interested to know his/her face beauty was made to stand on a platform and light from a lamp was made to fall on his/her face. The reading of complexion meter indicated the face beauty of the student which might be very fair, fair, semi fair, semi dark and dark etc.



(i) What is the basic concept used in the working of complexion meter?

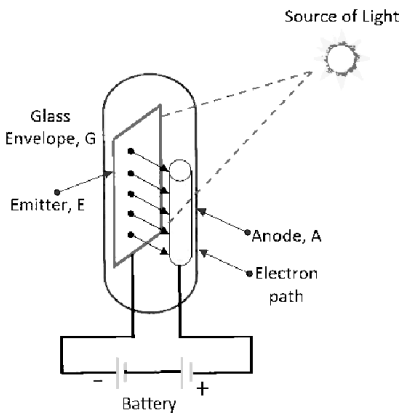
(ii) How is the face beauty recorded by face complexion meter?

Ans :

(i) The basic concept used in the working of complexion meter is photoelectric effect.

(ii) The reading of complexion meter depends on the current generated from the light reflected from the face. Fair the colour more is the light reflected and vice versa.

147. The photoelectric emission is possible only if the incident light is in the form of packets of energy, each having a definite value, more than the work function of the metal. This shows that light is not of wave nature but of particle nature. It is due to this reason that photoelectric emission was accounted by quantum theory of light.



1. What is the name of packet of energy ?
2. How much energy associated with each photon?
3. Which of the waves can produce photo electric effect?

Ans :

1. Quanta.
2. $h\mu$.
3. UV radiation.

148. Rekha's brother was riding the bike on highway and she was sitting behind him. While sitting, at a place traffic signal turned red from green and her brother continued riding without noticing the signal change. Rekha observed the whole situation and asked her brother to stop. Her brother felt happy on his sister's intelligence.

(i) What are the principles that are used in maintaining traffic signals?

(ii) What is the leading physical quantity in the process? Write an equation for the speed of the photoelectrons.

Ans :

(i) Principle of photoelectric effect is used to maintain the traffic signal.

(ii) The leading physical quantity of photoelectric current raised due to motion of photoelectrons. The required equation is

$$v = \sqrt{\frac{2E}{m} - \frac{2\phi}{m}}$$

Here, $v =$ speed of the electron, $E =$ energy of the photon, $m =$ mass of the electron and $\phi =$ work function for the metal.

149. Sandeep and his younger brother Vimal went to a shopping mall whose doors were automatic with self close and open. Vimal asked Sandeep that, "Why these doors are automatically opening and closing without even a single touch?" Sandeep was a graduate but, he did not know the exact reason behind this. Sandeep asked the same from his friend Rahul who was junior to him. Rahul explained the whole phenomenon agilerly to Sandeep and told that this whole phenomenon is based on photoelectric effect given by the great scientist Einstein.

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3. Angular momentum of an electron orbiting in the 3rd Bohr orbit of a hydrogen atom is

(a) $h/2\pi$ (b) $2h/2\pi$

(c) $3h/2\pi$ (d) $4h/2\pi$

Ans : **Main 2022 Sem-II**

Angular momentum of an electron orbiting in the nth Bohr orbit of a hydrogen atom is given as

$$L = \frac{nh}{2\pi}$$

For 3rd Bohr orbit, $n = 3$

$$L = \frac{3h}{2\pi}$$

Thus (c) is correct option.

4. According to classical theory, the path of an electron in Rutherford's atom is

(a) spiral (b) circular

(c) parabolic (d) straight line

Ans : **Comp 2018, 2016**

We know according to classical theory that the path of an electron in Rutherford's atom is spiral towards the nucleus due to the continuous loss of energy of electron.

Thus (a) is correct option.

5. In Bohr's model of hydrogen atom, radius of the first orbit of an electron is r_0. Then, radius of the third orbit is

(a) $r_0/9$ (b) r_0

(c) $3r_0$ (d) $9r_0$

Ans : **Main 2018**

According to the Bohr's model, the radius of third orbit, $r_3 = n^2 r_0$

$$r_3 = (3)^2 r_0 \qquad [n = 3]$$

$$r_3 = 9r_0$$

Thus (d) is correct option.

6. If E_P and E_K represent potential energy and kinetic energy respectively of an orbital electron, then according to Bohr's theory

(a) $E_K = -E_P/2$ (b) $E_K = E_P$

(c) $E_K = 2E_P$ (d) $E_K = 2E_P$

Ans : **Main 2015, 2013**

Since, according to Bohr's theory, kinetic energy (E_K) is equal to half of potential energy with negative sign.

i.e. $$E_K = -\frac{E_P}{2}$$

Thus (a) is correct option.

7. For an electron in the second orbit of Bohr's hydrogen atom, the moment of liner momentum is

(a) πh (b) $2\pi h$

(c) $\frac{h}{\pi}$ (d) $\frac{2h}{\pi}$

Ans : **Comp 2014**

Energy level of orbit, $n = 2$

We know from the Bohr's atomic model of hydrogen atom that moment of linear momentum of second orbit,

$$L = \frac{nh}{2\pi} = \frac{2h}{2\pi} = \frac{h}{\pi}$$

Thus (c) is correct option.

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8. Total energy of an electron in the ground state of hydrogen atom is – 13.6 eV. Its total energy when hydrogen atom is in the first excited state, is

(a) + 13.6 eV (b) + 3.4 eV

(c) – 3.4 eV (d) – 54.4 eV

Ans : **Main 2016**

The energy of electron in any state is given by

$$E_n = -\frac{13.6}{n^2}$$

For $n = 2$ (first excited state),

$$E_n = -\frac{13.6}{(2)^2} = -3.4 \text{ eV}$$

Thus (c) is correct option.

9. First line of Balmer series (H_α) in the spectrum of hydrogen is obtained when an electron of hydrogen atom goes from

(a) 2nd orbit to 1st orbit

(b) 2nd orbit to 3rd orbit

(c) 3rd orbit to 2nd orbit

(d) 3rd orbit to 1st orbit

Ans : **Main 2022 Sem-II**

In the hydrogen spectrum, the Balmer series is formed when an electron falls to the second orbit (n=2) from higher orbits. The first line of the Balmer series is produced when the electron jumps from the third orbit (n=3) to the second orbit (n=2).

Thus (c) is correct option.

10. White light is passed through sodium vapours contained in a thin walled glass flask and the transmitted light is examined with the help of spectrometer. The spectrum, so obtained is

(a) absorption spectrum

(b) solar spectrum

Ans : SQP 2011

Binding energy of electron in n^{th} orbit of hydrogen atom,

$$E_n = \frac{13.6}{n^2} \quad ...(1)$$

and radius of electron in n^{th} orbit of hydrogen atom.

$$r_n = \frac{\varepsilon_0 n^2 h^2}{\pi m e^2} \quad ...(2)$$

Multiplying equations (1) and (2),

$$E_n \times r_n = \left(\frac{13.6}{n^2}\right) \times \left(\frac{\varepsilon_0 n^2 h^2}{\pi m e^2}\right)$$
$$= \frac{13.6 \varepsilon_0 h^2}{\pi m e^2}$$

Thus, it is independent of n.

Thus (a) is correct option.

22. The energy E of a hydrogen atom with principal quantum no. n is given by $E = -\frac{13.6}{n^2}$ eV.

The energy ejected when the electron jumps from $n = 3$ state to $n = 2$ state of hydrogen is approximately

(a) 0.85 eV (b) 1.5 eV

(c) 1.9 eV (d) 3.4 eV

Ans : Comp 2024, 2002

Given,

Relation for energy, $E = -\frac{13.6}{n^2}$ eV

(where, n is quantum no.)

Initial energy level, $n_1 = 3$

Final energy level, $n_2 = 2$

the energy ejected when electron jumps from one energy state to another energy state,

$$E = -13.6\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$
$$= -13.6\left[\frac{1}{3^2} - \frac{1}{2^2}\right] = -13.6\left[\frac{1}{9} - \frac{1}{4}\right]$$
$$= -13.6 \times \frac{-5}{36} = 1.9 \text{ eV}$$

Thus (c) is correct option.

23. A hydrogen atom makes a transition $n = 5$ to $n = 1$orbit. The wavelength of photon from emitted is λ. The wavelength of photon emitted when it makes a transition from $n = 5$ to $n = 2$ orbit is

(a) $\frac{8}{7}\lambda$ (b) $\frac{16}{7}\lambda$

(c) $\frac{24}{7}\lambda$ (d) $\frac{32}{7}\lambda$

Ans : Main 2023

$$\frac{1}{\lambda} = R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

Where, R is the Rydberg constant.

Here, $n_2 = 5, n_1 = 1$

$$\frac{1}{\lambda} = R\left[1 - \frac{1}{25}\right] = R\left(\frac{24}{25}\right)$$

or $\lambda = \frac{25}{24R} = \frac{25}{24\lambda}$ ...(1)

Now, when $n_1 = 2, n_2 = 5$

$$\frac{1}{\lambda'} = R\left[\frac{1}{4} - \frac{1}{25}\right]$$
$$\frac{1}{\lambda'} = R\left(\frac{25-4}{100}\right) = R\left(\frac{21}{100}\right)$$
$$\lambda' = \frac{100}{21 \times R} = \frac{100 \times 24}{21 \times 25}\lambda$$
$$= \frac{32}{7}\lambda$$

Thus (d) is correct option.

24. As the electron in Bohr's orbit of hydrogen atom passes from state $n = 2$ to $n = 1$, the kinetic energy K and the potential energy u change as

(a) K four-fold and u two-fold

(b) K two-fold and u four-fold

(c) K two-fold and u also two-fold

(d) K four-fold and u also four-fold

Ans : Main 2018, 2015

Initial energy level, $n_1 = 2$

Final energy level, $n_2 = 1$

Kinetic energy of an electron in the n^{th} orbit,

$$K_n = \frac{me^4}{8\varepsilon_0^2 n^2 h^2} \propto \frac{1}{n^2}$$

and potential energy of an electron in the n^{th} orbit,

$$u_n = -\frac{me^4}{4\varepsilon_0^2 n^2 h^2} \propto -\frac{1}{n^2}$$

Therefore, $\frac{K_1}{K_2} = \left(\frac{n_2}{n_1}\right)^2$

$$= \left(\frac{1}{2}\right)^2 = \frac{1}{4}$$

or $K_2 = 4K_1$

Similarly, $\frac{u_1}{u_2} = \left(\frac{n_2}{n_1}\right)^2$

$$= \left(\frac{1}{2}\right)^2 = \frac{1}{4}$$

or $u_2 = 4u_1$

Thus (d) is correct option.

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17. In which of the following system will the radius of first orbit be minimum ?

(a) hydrogen atom

(b) deuterium atom

(c) singly ionized helium

(d) doubly ionized lithium

Ans : **Main 2018**

Energy level of first orbit, $n = 1$

We know from the Bohr's atomic model that radius of first orbit,

$$r = \frac{\varepsilon_0 h^2}{\pi m e^2 Z} \propto \frac{1}{Z}$$

We also know that atomic number of hydrogen atom ($_1H^1$), deuterium atom ($_1H^2$), singly ionized helium (He^+) and doubly ionized lithium (Li^{++}) are 1, 1, 2 and 3 respectively. Since the atomic no. of doubly ionized lithium is maximum, therefore radius of first orbit of doubly ionized lithium will be minimum.

Thus (d) is correct option.

18. If the energy of hydrogen atom in ground state is -13.6 eV, then its energy in the first excited state will be

(a) -3.4 eV (b) -6.8 eV

(c) -27.2 eV (d) -52.4 eV

Ans : **Main 2017**

Energy of hydrogen atom in ground state,

$$E_1 = -13.6 \text{ eV}$$

Energy level of a hydrogen atom in its first excited state,

$$n = 2$$

Therefore energy of hydrogen atom in first excited state,

$$E_2 = \frac{E_1}{n^2} = -\frac{13.6}{(2)^2}$$
$$= -3.4 \text{ eV}$$

Thus (a) is correct option.

19. Which state of triply ionised beryllium (Be^{+++}) has the same orbital radius as that of the ground state of hydrogen?

(a) $n = 1$ (b) $n = 2$

(c) $n = 3$ (d) $n = 4$

Ans : **Main 2018**

Radius of ionised beryllium = Radius of hydrogen atom.Energy level of ground state of hydrogen $n_1 = 1$.

We know that,

Atomic no. of hydrogen atom $Z_1 = 1$.

and atomic no. of beryllium atom $Z_2 = 4$.

We also know from the Bohr's atomic model that orbital radius of n^{th} orbit,

$$r_n = \frac{\varepsilon_0 n^2 h^2}{\pi m e^2 Z}$$

or $$n \propto \sqrt{Z}$$

Therefore, $$\frac{n_1}{n_2} = \sqrt{\frac{Z_1}{Z_2}}$$
$$= \sqrt{\frac{1}{4}} = \frac{1}{2}$$

or $$n_2 = 2n_1$$
$$= 2 \times 1 = 2$$

where, n_2 = Energy level of triply ionised beryllium

Thus (b) is correct option.

20. In the Bohr's atomic model, if the atomic radius of the first orbit is r_0, then radius of the fourth orbit is

(a) r_0 (b) $4r_0$

(c) $8r_0$ (d) $16r_0$

Ans : **Main 2008**

Given,

Atomic radius of first orbit, $r_1 = r_0$

Initial energy level, $n_1 = 1$

Final energy level, $n_2 = 4$

We know from the Bohr's atomic model that radius of n^{th} orbit,

$$r_n = \frac{\varepsilon_0 n^2 h^2}{\pi m e^2} \propto n^2$$

Therefore, $$\frac{r_1}{r_2} = \left(\frac{n_1}{n_2}\right)^2$$
$$= \left(\frac{1}{4}\right)^2 = \frac{1}{16}$$

Radius of fourth orbit,

$$r_2 = 16r_1 = 16r_0$$

Thus (d) is correct option.

21. In Bohr's atomic model of hydrogen atom, the product of binding energy of electron in n^{th} orbit and its radius in n^{th} orbit is

(a) independent of n

(b) proportional to n

(c) proportional to n^2

(d) inversely proportional to n

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For nth orbit, writing E_n for E, we have

$$E_n = -\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{2r_n}$$

After substituting the value of r_n, we get

$$E_n = -\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{2\left(\frac{\varepsilon_0 h^2 n^2}{\pi m Ze^2}\right)}$$

$$= -\frac{mZ^2e^4}{8\varepsilon_0^2 h^2 n^2}$$

For convenience introducing Rydberg constant,

$$R = \frac{me^4}{8\varepsilon_0^2 ch^3}$$

We have, $$E_n = \frac{Z^2 Rhc}{n^2}$$

For hydrogen atom, $Z = 1$

Energy of orbiting electron in H-atom,

$$E_n = -\frac{Rhc}{n^2}$$

$$E_n = -\frac{13.6}{n^2}\text{ eV}$$

The lowest energy of the atom is called the ground state, this state has lowest energy, The energy of this state is -13.6 eV. Therefore the minimum energy required to free the electron from the ground state of the hydrogen atom is -13.6 eV.

4. HYDROGEN SPECTRUM

Hydrogen emission spectrum consists of 5 series.

(a) **Lyman Series :** This lies in ultraviolet region.

(b) **Balmer Series :** This lies in the visible region.

(c) **Paschen Series :** This lies in near infrared region.

(d) **Brackett Series :** This lies in mid infrared region.

(e) **Pfund Series :** This lies in mid infrared region.

The atomic hydrogen emits a line spectrum consisting of various series. The frequency of any line in a series can be expressed as

(a) Lyman series,

$$v = R\left(\frac{1}{1^2} - \frac{1}{n^2}\right);\ n = 2, 3, 4...$$

[Shortest wavelength $= 911.6$ Å, Longest wavelength 1215 Å]

(b) Balmer series,

$$v = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right);\ n = 3, 4, 5...$$

[Shortest wavelength $= 3646$ Å Longest wavelength $= 6563$ Å]

(c) Paschen series,

$$v = R\left(\frac{1}{3^2} - \frac{1}{n^2}\right);\ n = 4, 5, 6, ...$$

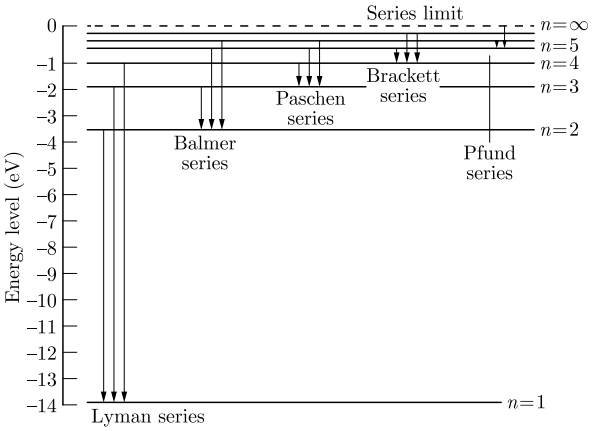
[Shortest wavelength 8204 Å Longest wavelength $= 18752$ Å].

(d) Brackett series,

$$v = R\left(\frac{1}{4^2} - \frac{1}{n^2}\right);\ n = 5, 6, 7...$$

(e) Pfund series,

$$v = R\left(\frac{1}{5^2} - \frac{1}{n^2}\right);\ n = 6, 7, 8$$



OBJECTIVE QUESTIONS

1. Rutherford's α-particle experiment showed that the atoms have

(a) proton (b) nucleus

(c) neutron (d) electrons

Ans : **SQP 2021**

We know from the Rutherford's α particle experiment that the atoms have nucleus and the nucleus contains atoms all the mass of an atom.

Thus (b) is correct option.

2. Which series comes in visible region of hydrogen spectrum?

(a) Lyman series (b) Balmer series

(c) Paschen series (d) Bracket series

Ans : **Main 2013**

When an electron jumps from n^{th} orbit to second orbit in an hydrogen atom then the series emitted is blamer series is in visible region.

Thus (b) is correct option.

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ASSERTION AND REASON

DIRECTION : These questions consist of two statements, each printed as Assertion and Reason. While answering these questions, you are required to choose any one of the following five responses.

25. **Assertion :** Bohr had to postulate that the electrons in stationary orbits around the nucleus do not radiate.

Reason : According to classical physics all moving electrons radiate.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Main 2014**

Bohr postulated that electrons in stationary orbits around the nucleus do not radiate. This is the one of Bohr's postulate. According to this the moving electrons radiates only when they go from one orbit to the next lower orbit.

Thus (b) is correct option.

26. **Assertion :** The specific charge of positive rays is not constant.

Reason : The mass of ions varies with speed.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **SQP 2018, 2015**

The specific charge $\frac{e}{m}$ of positive ray is not constant

because for different velocities the rest mass of particles change i.e. mass of ions varies with speed. So $\frac{e}{m}$ will differ.

Thus (a) is correct option.

27. **Assertion :** Balmer series lies in the visible region of the electrons radiate.

Reason : $\frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{n^2}\right]$, where $n = 3, 4, 5$

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Main 2024**

Wavelength is Balmer series is,

$$\frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{n^2}\right]$$

$$\frac{1}{\lambda_{max}} = R\left[\frac{1}{2^2} - \frac{1}{3^2}\right]$$

or $$\lambda_{max} = \frac{36}{5R} = \frac{36}{5 \times 1.097 \times 10^7}$$

$$= 6563 \text{ Å}$$

$$1/\lambda_{min} = R\left[\frac{1}{2^2} - \frac{1}{\infty^2}\right]$$

or $$\lambda_{min} = \frac{4}{R} = \frac{4}{1.097 \times 10^7}$$

$$= 3646 \text{ Å}$$

So it lies in the visible region.

Thus (b) is correct option.

28. **Assertion :** Between any two given energy levels, the number of absorption transitions is always less than the number of emission transitions.

Reason : Absorption transitions start from the lowest energy level only and may end at any higher energy level. But emission transitions may start from any higher energy level and end at any energy level below it.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

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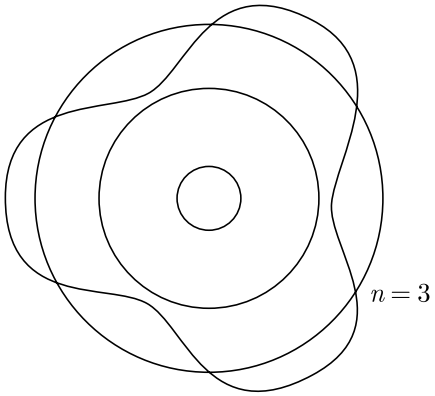
Substituting value of λ from eq. (2) in eq.(1), we get

$$2\pi r = n\frac{h}{mv}$$

$$mvr = n\frac{h}{2\pi} \quad ...(3)$$

This is Bohr's postulate of quantisation of energy levels.



THREE MARKS QUESTIONS

58. State Bohr postulate of hydrogen atom that gives the relationship for the frequency of emitted photon in a transition.

Ans : **Main 2014, 2013**

Bohr's third postulate it states that an electron might make a transition from one of its specified non-radiating orbits to another of lower energy. When it does so, a photon is emitted having energy equal to the energy difference between the initial and final states. The frequency of the emitted photon is given by

$$h\nu = E_i - E_f$$

Where, E_i and E_f are the energies of the initial and final states and $E_i > E_f$.

59. On the basis of Bohr's theory, derive an expression for the radius of the nth orbit of an electron of hydrogen atom.

Ans : **Main 2022 Sem-II**

Let the electrons of mass m be moving with a velocity vn in an orbit of radius r around the nucleus of hydrogen carrying a charge $+ e$. Since the electrostatic force between the electron and proton supplies the necessary electrostatic force.

According to angular momentum postulate

$$k \cdot \frac{e^2}{r_n^2} = m\frac{v_n^2}{r_n}$$

$$r_n = \frac{ke^2}{mv_n^2} \quad ...(1)$$

Putting this value of v_n in eq. (1)

$$r_n = \frac{ke^2}{mn^2h^2} \cdot 4\pi^2 m r_n^2$$

$$r_n = \frac{n^2h^2}{4\pi^2 ke^2}$$

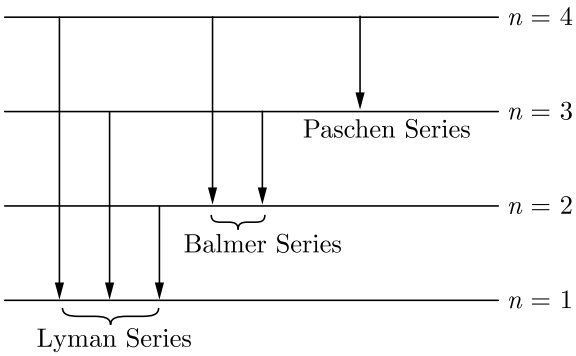
Which is the required expression

Clearly, $r_n \propto n^2$

60. An electron jumps from fourth to first orbit in an atom. How many maximum number of spectral lines can be emitted by the atom? To which series these lines correspond?

Ans : **SQP 2017, 2011**

Electron jumps from fourth to first orbit in an atom :



Maximum number of spectral lines can be

$$4_{C_2} = \frac{4!}{2!2!}$$

$$= \frac{4 \times 3}{2}$$

$$= 6$$

The line responds to Lyman series (e^- jumps to 1st orbit), Balmer series (e^- jumps to 2nd orbit), paschen series (e^- jumps to 3rd orbit).

61. (i) Name a series of lines of hydrogen spectrum which lies in

(a) visible region,

(b) UV region.

(ii) Write Bohr's formula to calculate wavelength (λ) of visible light emitted by hydrogen and explain the meaning of each and every symbol used.

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TWO MARKS QUESTIONS

39. How are various lines of Lyman series formed? Explain on the basis of Bohr's theory.

Ans : **Main 2015**

Bohr postulated that Lyman series is obtained when an electron jumps to first orbit $(n_1 = 1)$ from any outer orbit $(n_2 = 2, 3, 4, ...)$.

Wave numbers of spectral lines of Lyman series can be calculated as

$$\overline{v} = R\left[\frac{1}{1^2} - \frac{1}{n_2^2}\right], \text{ where } n_2 = 2, 3, 4, ...$$

40. Why is the classical (Rutherford) model for an atom of electron orbiting around the nucleus not able to explain the atomic structure?

Ans : **Main 2007**

The classical model could not explain the stability of atom as the negatively charged electrons are revolving around the nucleus are accelerated and emits energy as the result, the radius of the electrons on circular paths goes on decreasing. Ultimately, electrons fall into the nucleus, which is not true for an atom.

41. Why is the classical Rutherford model for an atom of electron orbiting around the nucleus not able to explain the atomic structure?

Ans : **Main 2025**

The classical method could not explain the atomic structure as the electron revolving around the nucleus are accelerated and emits energy as the result, the radius of the circular paths goes on decreasing. Ultimately electrons fall into the nucleus, which is not in practical.

42. Define ionization energy. How would the ionization energy change when electron in hydrogen atom is replaced by a particle of mass 200 times that of the electron but having the same charge?

Ans : **SQP 2019**

The minimum energy, required to free the electron from the ground state of the hydrogen atom, is known as ionization energy.

$$E_0 = \frac{me^4}{8\varepsilon_0^2 h^2},$$

i.e., $E_0 \propto m$

Therefore, ionization energy will become 200 times.

43. Consider two different hydrogen atoms. The electron in each atom is in an excited state. Is it possible for the electrons to have different energies but the same orbital angular momentum according to the Bohr model?

Ans : **Comp 2014**

According to Bohr model electrons having different energies belong to different levels having different values of n. So, their angular momenta will be different, as

$$L = \frac{nh}{2\pi} \text{ or } L \propto n$$

44. With reference to Nuclear Physics, answer the following questions

(i) What is meant by "Isotopes"?

(ii) Define 1u (where u stands for unified atomic mass unit.)

Ans : **Main 2023**

(i) The atoms of element whose nuclei have the same number of protons but different number of neutrons or they have same atomic number but different mass number are called the isotopes.

(ii) Atomic mass unit is defined as one-twelfth of the mass of one carbon atom $({}_6C^{12})$ isotope.

i.e. $1 \text{ amu} = \frac{1}{12}$ (mass of a carbon atom)

45. What conclusion was drawn by Rutherford based on Geiger Marsden's experiment on scattering of α-particles?

Ans : **Main 2012**

On the basis of Geiger-Marsden's experiment, Rutherford concluded that

(i) most of space inside the atom is empty .

(ii) at the centre of atom there is a small space, where the whole of positive charges is concentrated.

(iii) the space where only positive charge particle is concentrated is called nucleus.

46. State Bohr's quantisation condition for defining stationary orbits.

Ans : **SQP 2024, 2011**

According to Bohr's quantisation condition, electrons are permitted to revolve in only those orbits in which the angular momentum of electron is an integral multiple of $\frac{h}{2\pi}$ i.e.,

$$mvr = \frac{nh}{2\pi}$$

Where, $n = 1, 2, 3, ...$

m, v, r are mass, speed and radius of electron respectively and h being Planck's constant.

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Limitations of Rutherford's Atomic Model

Rutherford's model has two main difficulties in explaining the structure of atom:

1. It predicts that atoms are unstable because the accelerated electrons revolving around the nucleus must radiate energy and move spirally into the nucleus. This contradicts the stability of matter.
2. It cannot explain the characteristic line spectra of atoms of different elements.

72. Dictate the following terms.

(i) Isotopes

(ii) Isobars

(iii) Isotones

Ans : **Main 2018, 2015**

(i) **Isotopes :** The atoms of element whose nuclei have the same number of protons but different number of neutrons or we can say that they have same atomic number but different mass number are called the 'isotopes' of that element. The isotopes of some elements are as
Hydrogen : ${}_1H^1$ (proton), ${}_1H^2$ (deuterium), ${}_1H^3$ (tritium)
Oxygen : ${}_8O^{16}$, ${}_8O^{17}$, ${}_8O^{18}$
Neon : ${}_{10}Ne^{20}$, ${}_{10}Ne^{21}$, ${}_{10}Ne^{22}$
Chlorine : ${}_{17}Cl^{35}$, ${}_{17}Cl^{37}$
Uranium : ${}_{92}U^{235}$, ${}_{92}U^{238}$

(ii) **Isobars :** The nuclei which have the same number of, nucleons (i.e. mass number), but different number of protons and different number of neutrons are called 'isobars'. Their atomic numbers (Z) are different, but mass number (A) is same. The nuclei of isobars belong to the different elements. Some examples of isobars are as
${}_1H^3$ and ${}_2He^3$, ${}_{11}Na^{23}$ and ${}_{12}Mg^{23}$

(iii) **Isotones :** The nuclei having equal number of neutrons are called 'isotones'. For them, both the atomic number (Z) and the mass number (A) are different, but the value of $(A - Z)$ is same. Some examples of isotones are as
${}_3Li^7$ and ${}_4Be^8$, ${}_{17}Cl^{37}$ and ${}_{19}K^{39}$, ${}_{11}Na^{23}$ and ${}_{12}Mg^{24}$

73. Define the terms excitation and ionisation energies; and excitation and ionisation potentials.

Ans : **SQP 2019**

Excitation Energy : The excitation energy of an atom is defined as the energy required by its electron to jump from the ground state to any one of the excited states.

First excitation energy of hydrogen

$$= E_2 - E_1 = -3.4 - (-13.6) = 10.2\,\text{eV}$$

Ionisation Energy : It is defined as the energy required to knock an electron completely out of the atom, i.e., the energy required to take an electron from its ground state to the outermost orbit ($n = \infty$). After the removal of the electron, the atom is left with positive charge and it is said to ionised.

Ionisation energy of hydrogen

$$= E_\infty - E_1 = 0 - (-13.6) = 13.6\,\text{eV}$$

Excitation Potential : It is that accelerating potential which gives to a bombarding electron, sufficient energy to excite the target atom by raising one of its electrons from an inner to an outer orbit.

First excitation potential of hydrogen

$$= -3.4 - (-13.6) = 10.2\,\text{V}$$

Second excitation potential of hydrogen

$$= -1.51 - (-13.6) = 12.09\,\text{V}$$

Ionisation Potential : It is that accelerating potential which gives to a bombarding electron, sufficient energy the target atom by knocking one of its electrons completely out of the atom.

Ionisation potential of hydrogen

$$= 0 - (-13.6) = 13.6\,\text{V}$$

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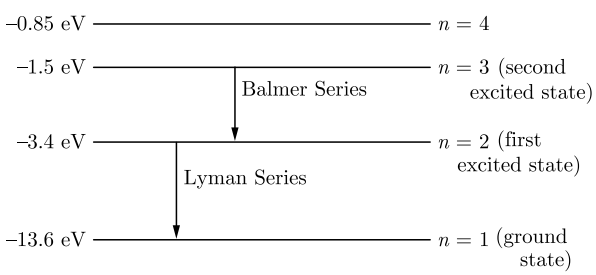
74. (i) In hydrogen atom, an electron undergoes transition from second excited state to the first excited state and then to the ground state. Identify the spectral series to which these transitions belong.

(ii) Find out the ratio of the wavelength of the emitted radiations in the two cases.

Ans : **Main 2012**

(i) An electron undergoes transition from second excited state to the first excited state is Balmer series and then to the ground state is Lyman series.

(ii) The wavelength of the emitted radiations in the two cases.



angular momentum of an electron is an integral multiple of $\frac{h}{2\pi}$ where, h is Plank's constant,

i.e., $L = mvr = \frac{nh}{2\pi}$

Where, m = mass of electron

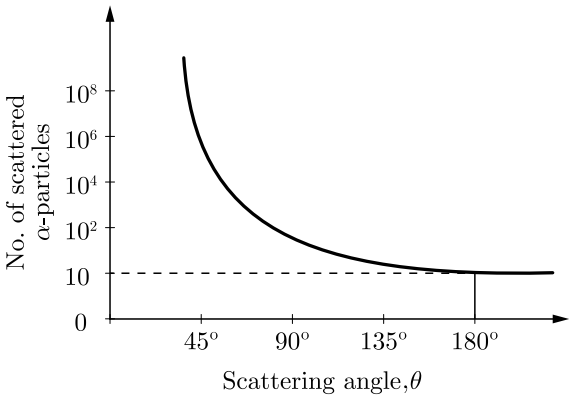
v = speed of electron

and r = radius of orbit of electron

$$2\pi r = n\left(\frac{h}{mv}\right)$$

Circumference of electron in n^{th} orbit $= n \times$ de-Broglie wavelength associate with electron.

54. In an experiment of α-particle scattering by a thin foil of gold, draw a plot showing the number of particle scattered versus the scattering angle θ. Why is it that a very small fraction of the particles are scattered at $\theta > 90^\circ$?



Ans : **SQP 2013**

A small fraction of the alpha particles scattered at angle $\theta > 90^\circ$ is due to the reason.

That if impact parameter 'b' reduces to zero, coulomb force increases, hence, alpha particles are scattered at angle $\theta > 90^\circ$ and only one alpha particle is scattered at angle 180°.

55. According to Bohr, 'angular momentum of an orbiting electron is quantised'. What is meant by this statement?

Ans : **Main 2017**

According to Bohr, 'angular momentum of an orbiting electron is quantised' - it means of all the possible circular orbits, the electrons are permitted to circulate only in those orbits in which the angular momentum of an electron is an integral multiple of $\frac{h}{2\pi}$, h being

Planck's constant.

Therefore, for any permitted orbit,

$$L = mvr = \frac{nh}{2\pi},\ n = 1, 2, 3,....$$

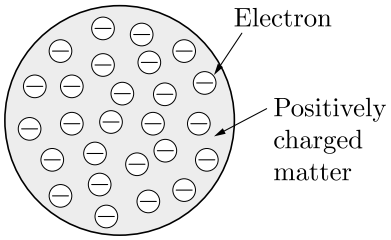
where L, m and v are the angular momentum, mass and the speed of the electrons, r is the radius of the permitted orbit and n is positive integer called principal quantum number.

Thus, the angular momentum of the orbiting electron is quantised has certain value $\frac{nh}{2\pi}$.

56. Briefly describe Thomson's modal of an atom, Why was this model discarded later on?

Ans : **SQP 2020**

Thomson's Model of an Atom : An atom consists of a sphere of positively charged matter in which the negatively charged electrons are uniformly embedded like the plums in a pudding, as shown in figure. The mutual repulsions between electrons are balanced by their attractions with the positively charged matter. Thus the atom as a whole is stable and neutral.



Failure of Thomson's Model : Thomson model was discarded due to the following drawbacks:

1. It could not explain the origin of several spectral series in the case of hydrogen and other atoms.
2. It failed to explain the large angle scattering of α-particles in Rutherford's experiment.

57. Using de-Broglie's hypothesis, explain with the help of a suitable diagram, Bohr's second postulate of quantisation of energy levels in a hydrogen atom.

Ans : **Main 2014**

According to de-Broglie's hypothesis.

$$\lambda = \frac{h}{mv} \quad ...(1)$$

According to de Broglie's condition of stationary orbits, the stationary orbits are those which contain complete de-Broglie wavelength.

$$2\pi r = n\lambda \quad ...(2)$$

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Which of the transitions belong to lyman and balmer series? Calculate the ratio of the shorter wavelengths of the lyman and the balmer series of the spectra.

Ans : SQP 2015, 2011

Transition C and E belong to lyman series.

Reason : In lyman series, the electron jumps to lowest energy level from any higher energy levels.

ransition B and D belong to balmer series.

Reason : The electron jumps from any higher energy level to the level just above the ground energy level. The wavelength associated with the transition is given by,

$$\lambda = \frac{hc}{\Delta E}$$

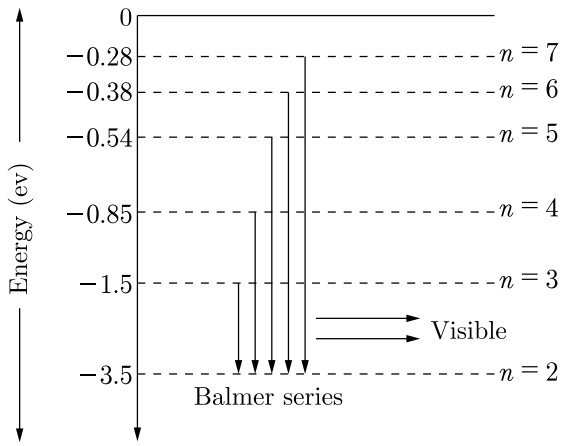
Ratio of the shortest wavelength

$$\lambda_L : \lambda_B = \frac{hc}{\Delta E_L} : \frac{hc}{\Delta E_B}$$

$$\frac{1}{0-(-10)} : \frac{1}{0-(-3)} = 3 : 10$$

66. Draw energy level diagram for hydrogen atom showing at least four lowest energy levels. Show the transitions responsible for emission of Balmer series.

Ans : SQP 2018



For Balmer series $\bar{v} = \frac{1}{\lambda} R\left[\frac{1}{2^2} - \frac{1}{n^2}\right]$

$$n = 3, 4, 5, \ldots$$

Clearly, when an electron goes from higher energy level to lower energy level, it loses some energy which is released in the form of photons.

67. Differentiate between line, band and continuous spectra. What type of substances give rise to these spectra?

Ans : Main 2007

The difference between line,band and continuous spectra are as follows :

Continuous Spectra	Band Spectra	Line Spectra
It contains all the wavelengths from one end to other without any gap.	It is given by chemical compounds (e.g., by CO_2 or ammonia gas in discharge tube.)	It is formed by light emitted by atoms of elements in vapour phase.
It is due to light from incandescent solid dense luminous gas. The flame spectrum is unbroken.	The large number of luminous band is present. Bands are sharply defined.	It consists of bright lines in different regions. All the lines do not have same intensity.
The colour of band changes from point to point.	Each band consists of a large number of lines being more crowded at the sharp edge and gradually fade away.	It is discontinuous spectrum. Each line corresponds to particular wavelength.

68. State any two Bohr's postulate and write the energy value of the ground state of the hydrogen atom.

Ans : Main 2025

The two postulates are as follows :

(i) Bohr's first postulate was that an electron in an atom could revolve in certain stable orbits without the emission of radiant energy, contrary to the predictions of electromagnetic theory. According to this postulate, each atom has certain definite stable states in which it can exist and each possible state has definite total energy. These are called the stationary states of the atom.

(ii) Bohr's second postulate states that the electron revolves around the nucleus only in those orbits for which the angular momentum is some integral multiple of $h/2\pi$, where h is the Planck's constant $(= 6.63 \times 10^{-34}\,\text{J} - \text{s})$ Thus, the angular momentum (L) of the orbiting electron is quantised,

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Ans : **Main 2011**

(i) (a) Balmer series of lines of hydrogen spectrum lies in visible spectrum.

(b) Lyman series of hydrogen spectrum lies in UV region.

(ii) For hydrogen atom,

$$\frac{1}{\lambda} = Z^2R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

where, λ = wavelength

R = Rydberg constant

n_1 = lower energy state

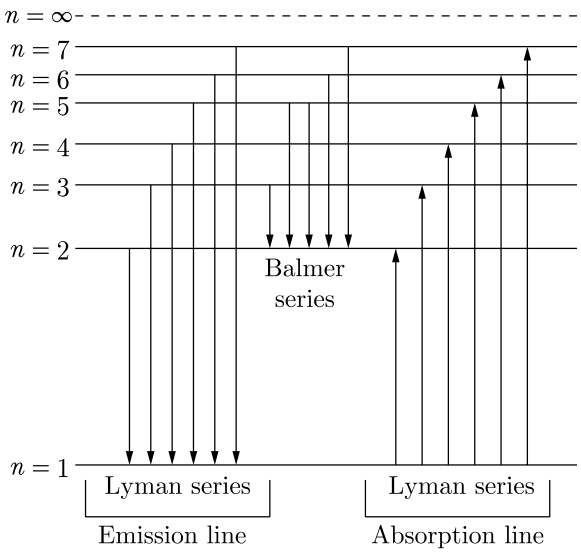
n_2 = higher energy state.

62. Draw the energy level diagram of a hydrogen atom and draw arrows to show transitions responsible for

(i) absorption lines by Lyman series

(ii) emission lines by Balmer series.

Ans : **Main 2024**



63. How the size of a nucleus is experimentally determined? Write the relation between the radius and mass number of the nucleus. Show that the density of nucleus independent of its mass number.

Ans : **Main 2013, 2009**

The size of nucleus will increase of mass number. The size of the nucleus is experimentally determined using Rutherford's α-scattering experiment and the distance of closest approach and impact parameter.

The relation between radius and mass number of nucleus is $R = R_0A^{1/3}$

where, $R_0 = 1.2\,\text{Fm}$

A = mass number

and R = radius of nucleus

Nuclear density, $\rho = \dfrac{\text{Mass of nucleus}}{\text{Volume of nucleus}}$

$$= \frac{mA}{\frac{4}{3}\pi\left(R_0A^{1/3}\right)^3}$$

where, m = mass of each nucleon

$$\rho = \frac{mA}{\frac{4}{3}\pi R_0^3 A}$$

$$= \frac{m}{\frac{4}{3}\pi R_0^3} = \text{constant}$$

64. Draw a level diagram of hydrogen, shown by a downward or an upward arrow, a transition which results in

(i) emission line of Balmer series.

(ii) emission line of Lyman series.

(iii) absorption line of Lyman series.

The diagram is given as below.

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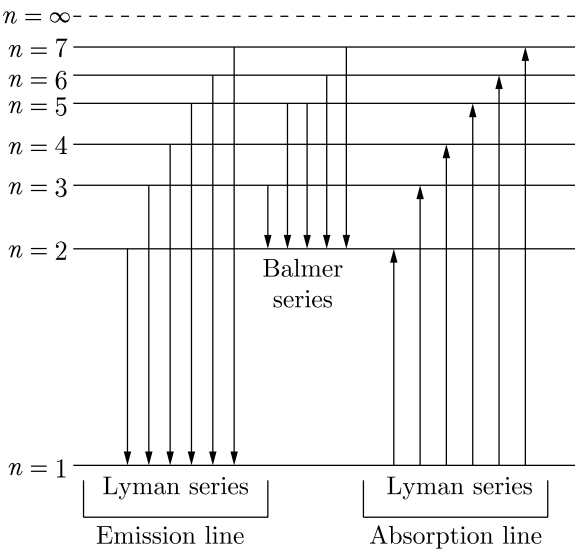
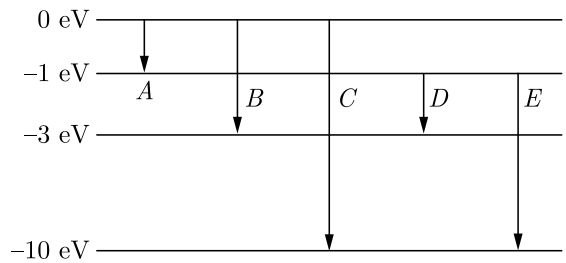
Ans : **Main 2010**



65. The energy levels of an atom are given below in the diagram.



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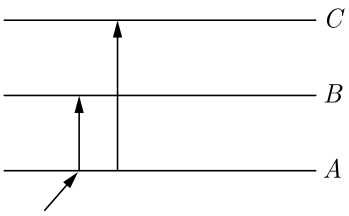
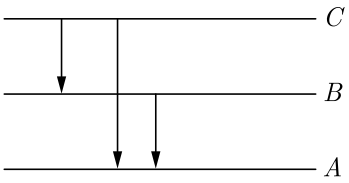
Ans : **Main 2010**

Absorption transition



Two possibilities in absorption transition.



Three possibilities in emission transition.

Therefore, absorption transition $<$ emission.

Thus (a) is correct option.

ONE MARK QUESTIONS

29. If a hydrogen atom goes from III excited state to II excited state, what kind of radiation is emitted?

Ans : **Main 2009**

It produces visible spectrum.

30. Name the series of lines in the hydrogen spectrum which lies in the ultraviolet region.

Ans : **Main 2025**

Lyman series lies in ultraviolet region in hydrogen spectrum.

31. Where is H_α-line of the balmer series in the emission spectrum of hydrogen atom obtained?

Ans : **Comp 2018, 2015**

H_α-line of the balmer series in the emission spectrum of hydrogen atom is obtained in visible region.

32. Mention any one postulate of Bohr's theory of hydrogen atom.

Ans : **Main 2007**

Electron can revolve only in those orbits in which its angular momentum is an integral multiple of $h/2\pi$, [$h =$ Planck's constant].

33. Define 'unified atomic mass unit'.

Ans : **Main 2009**

Atomic mass unit is defined as one-twelfth of the mass of one carbon atom ($_6C^{12}$) isotope.

i.e. $1 \text{ amu} = \frac{1}{12}$ (mass of a carbon atom)

34. Describe absorption spectrum of sodium.

Ans : **Main 2009**

When sodium atoms absorb energy. The energy absorbed by sodium atom is equivalent to the corresponding wavelength. Thus, it shows absorption spectrum and it emits a line spectrum of 589.6 nm of wavelength.

35. How is the radius of a nucleus related to its mass number?

Ans : **Main 2015, 2010**

Radius of nucleus, $R = R_0 A^{1/3}$

where, $R =$ radius of nucleus,

$A =$ mass number

and $R_0 = 1.2\,\text{Fm} = 1.2 \times 10^{-15}\,\text{m}$

36. Define ionisation energy. What is its value for a hydrogen atoms?

Ans : **SQP 2024**

The minimum amount of energy required to remove an electron from the ground state of the atom is known as ionisation energy.

Ionisation energy for hydrogen atom $= E_\infty - E_1$

$$= -(-13.6\,\text{eV}) = 13.6\,\text{eV}$$

37. Wavelengths of the first lines of the Lyman series, Paschen series and Balmer series, in hydrogen spectrum are denoted by λ_L, λ_P and λ_B respectively. Arrange these wavelengths in increasing order.

Ans : **Main 2024, 2015**

The arrangement of different series of wavelength in increasing order is that

$$\lambda_P > \lambda_B > \lambda_L$$

38. What is a continuous emission spectrum? Name one source of light which produces such a spectrum.

Ans : **Main 2010**

Continuous spectra contains all the wavelengths from one end to other without any gap. It is due to light from incandescent solid luminous gas flame. The spectrum is unbroken in this case. The colour of band changes from point to point.

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i.e. $L = \frac{nh}{2\pi}$

As, angular momentum of electron $= mvr$
For any permitted (stationary) orbit,

$$mvr = \frac{nh}{2\pi}$$

Where, $n =$ any positive integer 1, 2, 3,...
It is also called principal quantum number.
The energy value of the ground state of the hydrogen atom, $E = -13.6$ eV

69. State the postulate of Bohr's regarding

(i) angular momentum of an electron.

(ii) emission of photon.

(iii) total energy of an electron orbiting around the nucleus of an atom is always negative. What is the significance of this?

Ans : **Main 2013**

(i) The orbit in which electron revolves has fixed angular momentum or it is integral multiple of $\frac{h}{2\pi}$
i.e., $L = mvr = \frac{nh}{2\pi}$ $[n = 0,1,2,3,4]$

(ii) The electron can jump from one stationary orbit to other. If it jumps from an orbit from higher energy to lower energy, it emits photons and when it jump from lower energy to higher energy, it absorb photon.
The photon emitted or absorbed is in contrast with the energy difference between the stationary orbits i.e., if E_1 is the energy of stationary orbit, where electron is initially present and E_2 is the energy of stationary orbit to which it has jumped, then

$$E_1 - E_2 = \frac{hc}{\lambda}$$

where, λ is the wavelength of photon.

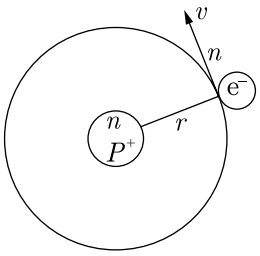
(iii) Total energy of electrons orbiting around nucleus is negative. This signifies that when electron is in free state it has zero energy. In other words, we can say that there is mutual attractive force between electron and nucleus which bind them together.

70. Obtain an expression for the kinetic energy of the electron in the Bohr's model of hydrogen atom ($Z = 1$). Start from equating the electrostatic force with the centripetal force required and then use the quantisation condition for angular momentum.

Ans : **Main 2003**

Assuming mass, charge and velocity of electron are m, e and v, respectively and r will be the radius of Bohr's orbit.

From the given diagram, for circular motion of an electron around nucleus, centripetal force must be equal to electrostatic the attraction.



So, $\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{Ze \times e}{r^2}$ ...(1)

$$L = mvr = \frac{nh}{2\pi} \quad ...(2)$$

$L =$ angular momentum

$[n =$ quantum number$]$

From Bohr's postulates of angular momentum of electrons.

Kinetic energy of electrons,

$$K = \frac{1}{2}mv^2 \quad ..(3)$$

So, from equation (1), (2) and (3), we get

$$K = \frac{1}{2}\left(\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r}\right)$$

This is the expression for the kinetic energy of the electrons in the Bohr's model of hydrogen.

71. Describe Rutherford's model of the atom. Give its limitations.

Ans : **Main 2024, 2020**

On the basis of the α-particle scattering experiment, Rutherford proposed the following model of an atom:

1. An atom consists of a small and massive central core in which the entire positive charge and almost the whole mass of the atom are concentrated. This core is called the nucleus.
2. The size of the nucleus ($\approx 10^{-15}$ m) is very small as compared to the size of atom ($\approx 10^{-10}$ m).
3. The nucleus is surrounded by a suitable number of electrons so that their total negative charge is equal to the total positive charge on the nucleus and the atom as a whole is electrically neutral.
4. The electrons revolve around the nucleus in various orbits just as planets revolve around the sun. The centripetal force required for their revolution is provided by the electrostatic attraction between the electrons and the nucleus.

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47. What is meant by ionisation energy ? Write its value for hydrogen atom.

Ans : SQP 2023, 2018

The ionization energy is the quantity of energy that an isolated, gaseous atom in the ground electronic state must absorb to discharge an electron, resulting in a cation. The energy is usually expressed in kJ/mol. It is also called a ionization potential, which is the amount of energy required to remove an electron from an isolated atom or molecule. The value of ionisation energy for hydrogen atom is 13.6 eV.

48. In the Rutherford scattering experiment, the distance of closest approach for an α-particle is d_0. If α-particle is replaced by a proton, how much kinetic energy in comparison to α-particle will be required to have the same distance of closest approach, d_0.

Ans : Main 2025, 2005

When α-particle is replaced by proton, then there will be a change in atomic number and mass of the particle.

For a given distance of closest approach,

Kinetic energy $\propto$ Z (charge on particle)

$$\frac{K_{\text{proton}}}{K_\alpha} = \frac{e}{2e} = \frac{1}{2}$$

[where, e is charge on proton]

$$K_{\text{proton}} : K_\alpha = 1:2$$

49. Define the term, mass defect. How is it related to stability of the nucleus?

Ans : SQP 2012

Mass defect is the difference between the actual atomic mass and the predicted mass. The actual mass of the atomic nucleus is always less than the mass of protons and neutrons present in the nucleus. When a nucleus is formed, energy is released. This energy is removed in the form of a reduction in total mass. This missing mass is known as the mass defect.

The mass defect can be calculated by subtracting the original atomic mass from the sum of the mass of protons and neutrons present in the nucleus.

50. Sate the drawbacks of Bohr's atomic theory.

Ans : Comp 2015

Drawback's of Bohr's atomic theory are as follows:

1. This model is applicable only to hydrogenic atoms. It cannot be extended to even two electron atoms such as He.
2. This model is unable to explain the relative intensities of the frequencies emitted by hydrogenic atoms.
3. It does not explain the fine structure of spectral lines even in hydrogen atom.
4. It does not explain why only circular orbits should be chosen when elliptical orbits are also possible.
5. It does not take into account the wave properties of electrons.

51. In the Rutherford scattering experiment, the distance of closest approach for an α-particles is d_0. If α-particles is replaced by a proton, then how much kinetic energy in comparison to α-particle will be required to have the same distance of closest approach d_0?

Ans : SQP 2017, 2009

Distance of closest approach,

$$d_0 = \frac{2kZe^2}{K_x} \qquad \left(\text{where}, k = \frac{1}{4\pi\varepsilon_0}\right)$$

Since, For given distance of closest approach,

Kinetic energy $\propto$ Z (atomic number)

$$\frac{K_{\text{proton}}}{K_\alpha} = \frac{Z_{\text{proton}}}{Z_\alpha} = \frac{1}{2}$$

$$K_{\text{proton}} : K_\alpha = 1:2$$

52. Write the expression for Bohr's radius in hydrogen atom.

Ans : Main 2015

Expression for Bohr's radius in hydrogen atom,

$$r = \frac{n^2h^2}{4\pi^2 mkZe^2}$$

$$r = \frac{n^2h^2}{4\pi^2 mke^2}$$

Where, n = principal quantum number

m = mass of electron

$k = \frac{1}{4\pi\varepsilon_0} = 9 \times 10^9 \text{N} - \text{m}^2/\text{C}^2$

Z = atomic number of atom = 1

h = Planck's constant

53. Using Bohr's second postulate of quantisation of orbital angular momentum show that the circumference of the electron in the nth orbital state in hydrogen atom is n-times the de-Broglie wavelength associated with it.

Ans : Main 2016

Bohr's second postulate states that the electron revolves around the nucleus in certain privileged orbit which satisfy certain quantum condition that

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For $n_2 \xrightarrow{\lambda_L} n_1$

$$\Delta E = (-3.40 + 13.6) = 10.20\,\text{eV}$$

$$\lambda_L = \frac{12.43 \times 10^{-7}}{10.2}$$

$$= 1.218 \times 10^{-7}\text{m}$$

$$\lambda_L = 1218\text{Å}$$

For $n_3 \xrightarrow{\lambda_B} n_2$

$$\Delta E = (-1.5 + 3.4)$$

$$= 1.9\,\text{eV}$$

$$\lambda_B = \frac{12.43 \times 10^{-7}}{1.9}$$

$$= 6.54 \times 10^{-7}\text{m}$$

$$= 6540\text{Å}$$

$$\frac{\lambda_B}{\lambda_L} = \frac{6540\text{Å}}{1281\text{Å}}$$

$$= 5.36$$

75. Using de-Broglie's hypothesis, explain with the help of a suitable diagram, Bohr's second postulate of quantization of energy levels in a hydrogen atom.

Ans : **Comp 2018**

Bohr's Quantization Condition of Angular Momentum : Consider the motion of an electron in a circular orbit of radius r around the nucleus of atom. According to de-Broglie hypothesis, this electron is also associated with wave character. Hence a circular orbit can be taken to be a stationary energy state only if it contains an integral number of de-Broglie wavelengths, i.e., we must have

$$2\pi r = n\lambda$$

But de-Broglie wavelength,

$$\lambda = \frac{h}{mv}$$

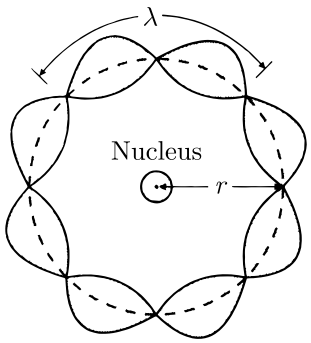
Hence, $$2\pi r = \frac{nh}{mv}$$

The angular momentum L of the electron must be,

$$L = mvr = \frac{nh}{2\pi}$$

$$n = 1, 2, 3 .....$$

This is the famous **Bohr's quantisation condition for angular momentum**. Thus only those circular orbits can be the allowed stationary states of an electron in which its angular momentum is an integral multiple of $\frac{h}{2\pi}$.

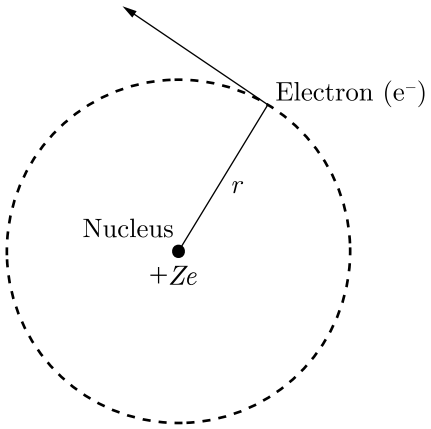


A Standing Wave of de-Broglie Wavelengths Fitting into a Circular Orbit of Radius r

76. On the basis of Bohr's theory, derive an expression for the radius of the nth orbit of an electron of hydrogen atom.

Ans : **Main 2014, 2011**

A hydrogen-like atom consists of a tiny positively charged nucleus and an electron revolving in a stable circular orbit around the nucleus.



Let e, m and v be respectively the charge, mass and velocity of the electron and r be the radius of the orbit. The positive charge on the nucleus is Ze, where Z is the atomic number. As, the centripetal force is provided by the electrostatic force of attraction, we have

$$\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0} = \frac{(Ze) \times e}{r^2}$$

or $$mv^2 = \frac{Ze^2}{4\pi\varepsilon_0 r} \quad ...(1)$$

From the second postulate, the angular momentum of the electron is

$$mvr = \frac{nh}{2\pi} \quad ...(2)$$

Where, $n =$ (1,2,3....) is the principal quantum number.

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From equation (1) and (2) , we get

$$r = \frac{n^2h^2\varepsilon_0}{\pi mZe^2}$$

This is the equation for the radii of the permitted orbit. According to this equation, $r_n = r_1 \times n^2$

Since, $n = 1, 2, 3, ...$

For Bohr radius, $n = 1$ and $Z = 1$

So, $$r_1 = \frac{h^2\varepsilon_0}{\pi me^2} = 0.53 \text{ Å}$$

77. Give the expression for the velocity of electron in the first orbit of hydrogen atom and the radius in the ground state of hydrogen atom. Hence, derive the expression for the magnetic field ($\vec{B}$) at the centre of the nucleus due to the circular motion of electron.

Ans : **Main 2003**

Let the radius of hydrogen atom be r and velocity of electron in this orbit is v.

So, from circular motion electrostatic force of attraction between nucleus and electrons is equal to the centripetal force of electrons.

$$\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q_1q_2}{r^2} \quad ...(1)$$

$$mvr = \frac{nh}{2\pi}$$

$$v = \frac{nh}{2\pi mr} \quad ...(2)$$

So, from Eqs. (1) and (2), we get

$$m\left(\frac{nh}{2\pi mr}\right)^2 = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r}$$

$$\frac{mn^2h^2}{4\pi^2m^2r^2} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r}$$

$$r = \frac{n^2h^2\varepsilon_0}{\pi me^2}$$

For ground state of hydrogen atom $n = 1$,

$$r = \frac{h^2\varepsilon_0}{\pi me^2}$$

The velocity of electrons is given by

For first orbit of hydrogen atom $n = 1$,

$$v = \frac{nh}{2\pi mr}$$

$$v = \frac{e^2}{2\varepsilon_0 h}$$

(ii) Revolving electron are considered as current loop whose magnetic field at centre is given by

$$B = \frac{\mu_0 ni}{2r} = \frac{\mu_0 ne}{2rt} \quad \left[\text{as } i = \frac{e}{t}\right]$$

$$= \frac{\mu_0 nev}{2r \times 2\pi r} \quad \left[\text{as } t = \frac{2\pi r}{v}\right]$$

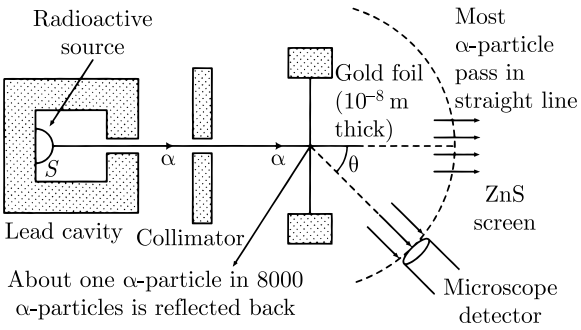
So, $$B = \frac{\mu_0 ne}{4\pi}\left[\frac{e^2}{2\varepsilon_0 nh}\Big/\left(\frac{n^2h^2\varepsilon_0}{\pi me^2}\right)^2\right]$$

$$= \frac{\mu_0\pi m^2e^7}{8\varepsilon_0^3h^5n^4} \text{ Wb/m}^2$$

78. In the study of Geiger-marsdon experiment on scattering of α-particles by a thin foil of gold, draw the trajectory of α-particles in the coulomb field of target nucleus. Explain briefly how can gets the information on the size of the nucleus from this study.

From the relation $R = R_0A^{\frac{1}{3}}$, where, R_0 is constant and A is the mass number of the nucleus, show that nuclear matter density is independent of A.

Ans : **Main 2013, 2010**



From this experiment, the following is observed.

(i) Most of the α-particles pass straight through the gold foil. It means that they do not suffer any collision with gold atoms.

(ii) About one α-particle in every 8000 α-particles deflects by more than 90°. As most of the α -particles go undeflected and only a few get deflected, this shows that most of the space in an atom is empty and at the centre of the atom, there exists a nucleus. By the number of α-particles get deflected, the information regarding size of the nucleus can be known.

If m is the average mass of the nucleus and R is the nuclear radius, then mass of nucleus $= mA$, where A is the mass number of the element.

Volume of the nucleus,

$$V = \frac{4}{3}\pi R^3 = \frac{4}{3}\pi(R_0A^{\frac{1}{3}})^3 = \frac{4}{3}\pi R_0^3A$$

Density of nuclear matter,

$$\rho = \frac{mA}{V} = \frac{mA}{\frac{4}{3}\pi R_0^3A} = \frac{3m}{4\pi R_0^3}$$

This shows that the nuclear density is independent of A.

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79. Draw energy level diagram for hydrogen atom, showing first four energy levels corresponding to $n = 1, 2, 3$ and 4. Show transitions responsible for

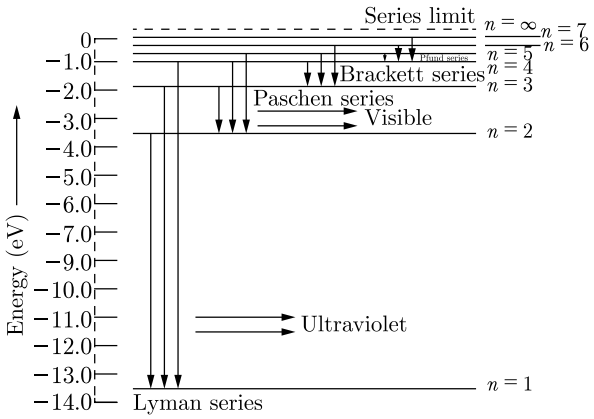
(i) Absorption spectrum of Lyman series.

(ii) Emission spectrum of Balmer series.

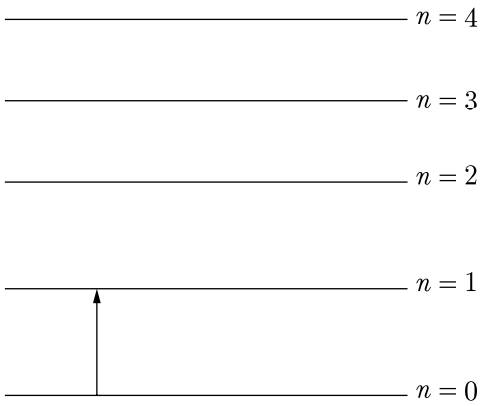
Ans : **Main 2020, 2016, 2008**

The energy level diagram of hydrogen atom is shown below. It consists of discrete bright lines in a dark background, known as emission spectrum.

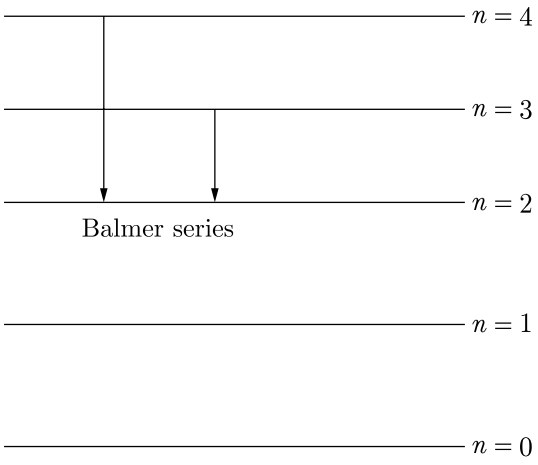
(i) The transistors responsible for absorption spectrum of Lyman series can be written from outer orbit to first orbit, hence it is in ultraviolet. Its shown below



Here, we get dark lines on the bright background. or Absorption spectrum of Lyman series. In Lyman series, the electrons jumps from outer orbit to first orbit. So, its absorption spectrum will be



(ii) Emission spectrum of Blamer series : In Blamer series, the electrons jumps from any outer orbit to the second orbit.

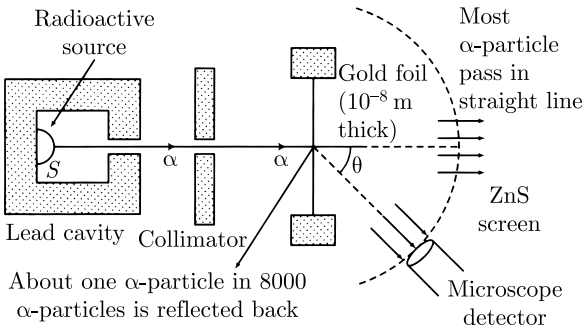


FOUR MARKS QUESTIONS

80. Draw a schematic arrangement of the Geiger-Marsden's experiment for studying α-particles scattering by a thin foil of gold. Describe briefly by drawing trajectories of the scattered α-particles. How this study can be used to estimate the size of the nucleus?

Ans : **Main 2010**

Given figure shows a schematic diagram of Geiger-Marsden's experiment.



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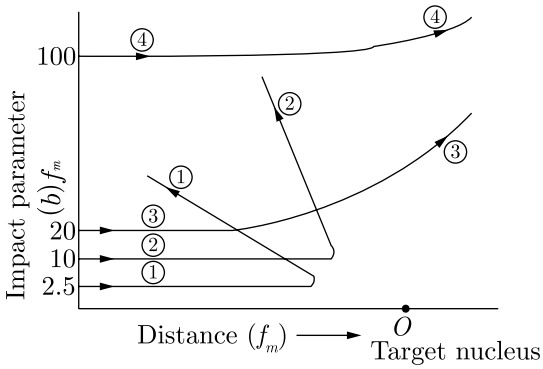


103. Determine the distance of closest approach when an alpha particle of kinetic energy 4.5 MeV strikes a nucleus of $Z = 80$, stops and reverse its direction.

Ans : SQP 2015

Let, r be the distance between the alpha particle and the nucleus ($Z = 80$). When the alpha particle is at the stopping point, then

$$E_K = \frac{1}{4\pi\varepsilon_0}\frac{(Ze)(2e)}{r}$$

$$r = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2Ze^2}{E_K}$$

$$= \frac{9\times10^9\times2\times80e^2}{4.5\,\text{MeV}}$$

$$= \frac{9\times10^9\times2\times80\times1.6\times10^{-19}}{4.5\times10^6}$$

$$= \frac{9\times160\times16}{4.5}\times10^{-16}$$

$$= 512\times10^{-16}\text{m} = 5.12\times10^{-14}\text{m}$$

104. A 12.5 eV electron beam is used to excite a gaseous hydrogen atom at room temperature. Determine the wavelength and the corresponding series of the lines emitted.

Ans : Main 2009

Given, $E = 12.5\,\text{eV} = 12.5\times1.6\times10^{-19}\text{J}$

$m = 9.1\times10^{-31}\,\text{kg}$

$h = 6.6\times10^{-34}\text{J-s}$

Hence, $P = \sqrt{2mE}$

$$P = \sqrt{2\times9.1\times10^{-31}\times12.5\times1.6\times10^{-19}}$$

$$\frac{h}{\lambda} = \sqrt{2\times9.1\times10^{-31}\times12.5\times1.6\times10^{-19}} \qquad \left(\because P = \frac{h}{\lambda}\right)$$

$$\lambda = \frac{h}{\sqrt{364\times10^{-50}}}$$

$$= \frac{6.6\times10^{-34}}{19.07\times10^{-25}} = 0.34\times10^{-19}\text{m}$$

$$= 3.4\times10^{-10}\text{m (Ultraviolet)}$$

105. An α-particle of energy 5 MeV is scattered through 180° by a fixed uranium nucleus. What is the order of distance of the closest approach?

Ans : Main 2012, 2015

Energy of α-particle,

$$E = 5\,\text{MeV}$$

$$= (5\times10^6)\times(1.6\times10^{-19})$$

$$= 8\times10^{-13}\,\text{J}$$

Atomic no. of uranium $Z = 90$.

We also know from the Rutherford's atomic model that distance of the closet approach,

$$r = k\times\frac{2Ze^2}{E}$$

Where, $k =$ Electrostatic force constant equal to 9×10^9

$$= (9\times10^9)\times\frac{2\times92\times(1.6\times10)^2}{8\times10^{-13}}$$

$$= 5.3\times10^{-14}\,\text{m} = 5.3\times10^{-12}\,\text{cm}$$

Therefore, distance to the closest approach is of the order of 10^{-12} cm.

106. Atomic radius of first orbit of hydrogen atom is 0.53 Å. What is the radius of its fifth orbit?

Ans : SQP 2009

Radius of first orbit, $r_1 = 0.53\,\text{Å}$;

Initial energy level, $n_1 = 1$ and

Final energy level, $n_2 = 5$

We know from the Bohr's atomic model that radius of n^{th} orbit,

$$r_n = \frac{\varepsilon_0 n^2h^2}{\pi me^2} \propto n^2$$

Therefore, $\frac{r_1}{r_2} = \left(\frac{n_1}{n_2}\right)^2$

$$= \left(\frac{1}{5}\right)^2 = \frac{1}{25}$$

or $r_2 = 25r_1 = 25\times0.53$

Radius of fifth orbit,

$$r_2 = 12.25\,\text{Å}$$

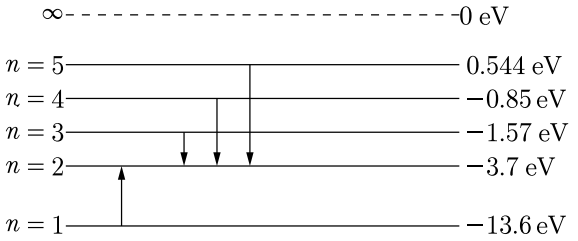
107. For Bohr's model of the hydrogen atom, the energy of the electron in ground state is found to be – 13.6 eV.

(i) Draw energy level diagram for the hydrogen atom and mark the values of energy (in eV at $n = 2$ and $n = \infty$).

(ii) Obtain the maximum energy of photon emitted by the hydrogen atom in eV.

Ans : Main 2005

(i) Energy diagram is given as follows



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$$= -\frac{21.76 \times 10^{-19}}{1.6 \times 10^{-19}} \text{ eV}$$

or $E_1 = -13.6$ eV [since $1\text{ eV} = 1.6 \times 10^{-19}$ J]

Hence we can write,

$$E_n = \frac{E_1}{n^2} = -\frac{13.6}{n^2} \text{ eV}$$

Setting $n = 2, 3, 4$, etc., we get the energies for the higher orbits as follows:

$$E_2 = \frac{-13.6}{2^2} = -3.4 \text{ eV}$$

$$E_3 = \frac{-13.6}{3^2} = -1.51 \text{ eV}$$

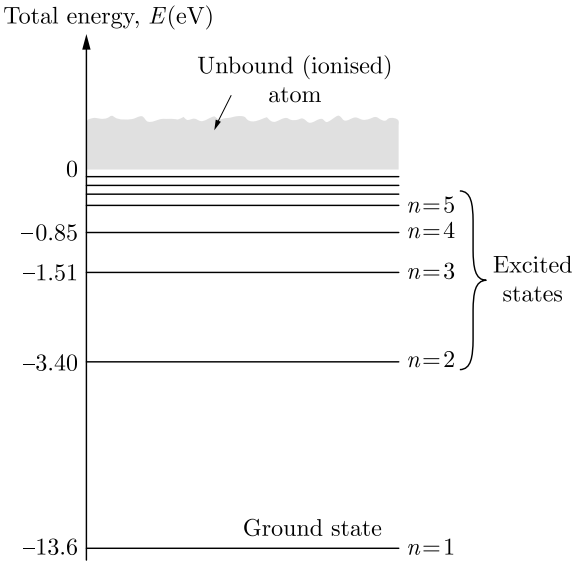
$$E_4 = \frac{-13.6}{4^2} = -0.85 \text{ eV}$$

$$E_5 = \frac{-13.6}{5^2} = -0.54 \text{ eV}$$

$$E_6 = \frac{-13.6}{6^2} = -0.37 \text{ eV}$$

Clearly, an electron can have only certain definite values of energy while revolving in different orbits. This is called energy quantisation.

The energy state corresponding to $n = 1$, has the lowest energy equal to -13.6 eV. This state is called the ground state of the atom. Normally the electron in the hydrogen atom remains in the ground state. When the hydrogen atom receives energy from outside by processes such as electron collisions, the electron may make transition to some higher energy state like E_2, E_3, E_4, etc. which are called the excited states. The energy level diagram for the hydrogen atom is shown in figure.



The Energy Level Diagram for H-atom

83. State the postulate of Bohr's model of hydrogen atom. Hence, derive the expression for the radius of nth orbit of electrons.

Ans : **Main 2010, 2002**

Bohr combined classical and early quantum concepts and gave his theory in the form of three postulates. These are

(i) Bohr's first postulate was that an electron in an atom could revolve in certain stable orbit without the emission of radiant energy contrary to the predictions of electromagnetic theory. According to this postulate, each atom has certain definite stable state, which has definite amount total energy associated with it. These are called the stationary states of the atom.

(ii) Bohr's second postulate defines these stable orbits. This postulate states that the electrons revolve around the nucleus only in those orbits for which the angular momentum is some integral multiple of $h/2\pi$, where h is the Planck's constant $(= 6.6 \times 10^{-34}\text{ J} - \text{s})$. Thus, the angular momentum (L) of the orbiting electron is quantised i.e., $L = \frac{nh}{2\pi}$

As angular momentum of electron

$$L = mvr$$

For any permitted (stationary) orbit

$$mvr = \frac{nh}{2\pi}$$

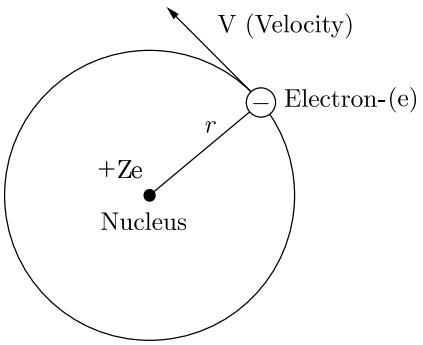
where, $n =$ any positive integer 1, 2, 3,....

It is also called principal quantum number.

(iii) Bohr's third postulate states that an electron might make a transition from one of its specified non-radiating orbits to another of lower energy. When it does so, a photon is emitted having energy equal to the energy difference between the initial and final states. The frequency of the emitted photon is then given by

$$h\nu = E_i - E_f$$

where, E_i and E_f are the energies of the initial and final states and $E_i > E_f$.



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91. The total energy of an electron in the first excited state of the hydrogen atom, is –3.4 eV. Find out its

(a) kinetic energy and

(b) potential energy in this state.

Ans : **Main 2021, 2017**

(a) Kinetic energy

$$= -\text{ Total energy}$$

$$= -(-3.4\,\text{eV}) = 3.4\,\text{eV}$$

(b) Potential energy

$$= -2 \times \text{Kinetic energy}$$

$$= -2 \times 3.4 = -6.8\,\text{eV}$$

92. From Bohr's energy quantisation formula, determine the largest wavelength in the Balmer series of hydrogen atom spectrum.

Ans : **Main 2006**

Energy is inversely proportional to the wavelength, so for largest wavelength in Balmer series, electron should fall from $n = 3$ to $n = 2$.

Now, according to the formula to calculate wavelength.

So, $\frac{1}{\lambda} = R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$ [$R =$ Rydberg constant]

$$\frac{1}{\lambda} = 1.097 \times 10^7\left(\frac{1}{4} - \frac{1}{9}\right) \quad [n_1 = 2,\ n_2 = 3]$$

$$\lambda = \frac{36 \times 10^{-7}}{1.097 \times 5} = 6563 \times 10^{-10}\,\text{m}$$

$$= 656.3\,\text{nm}$$

93. Calculate the shortest wavelength of electromagnetic radiation present in Balmer series of hydrogen spectrum.

Ans : **Main 2016**

The wavelength (λ) of different spectral lines of Balmer series is given by

$$\frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{n_2^2}\right]$$

For shortest wavelength, $n_2 = \infty$.

$$\frac{1}{\lambda} = 1.097 \times 10^7\left[\frac{1}{2^2} - \frac{1}{\infty}\right]$$

$$\frac{1}{\lambda} = \frac{1.097 \times 10^7}{4}$$

$$\lambda = \frac{4}{1.097 \times 10^7} = 3.646 \times 10^{-7}\,\text{m}$$

$$\lambda = 3646\,\text{Å}$$

94. What is the ratio of radii of the orbits corresponding to first excited state and ground state, in a hydrogen atom?

Ans : **Comp 2019, 2017**

For first excited states, $n = 2$

Ground state occurs for, $n = 1$

$$r_n = r_0 n^2$$

$$r \propto n^2$$

$$\frac{r_1}{r_2} = \left(\frac{n_1}{n_2}\right)^2 = \left(\frac{2}{1}\right)^2$$

Hence, $r_1 : r_2 = 4 : 1$

Where, r_1 and r_2 are radii corresponding to first excited state and ground state of the atom.

95. The energy of electron in first Bohr orbit of hydrogen atoms is -13.6 eV. What is energy of electron in its 2^{nd} Bohr-orbit?

Ans : **Comp 2016**

From Bohr's theory, the total energy of an electron in n^{th} orbit is given by,

$$E_n = \frac{2\pi^2 mk^2 e^4}{n^2 h^2}$$

$$= -13.6 n^2\,\text{eV} = \frac{E_1}{n^2}$$

Here, $E_1 = -13.6$

For $n = 2$, $E_n = \frac{E_1}{n^2} = -\frac{13.6}{(2)^2} = -3.4\,\text{eV}$

96. Calculate the wavelength of radiation emitted when electron in a hydrogen atom jumps from $n = \infty$ to $n = 1$.

Ans : **Comp 2025, 2013**

As we know that, $\frac{1}{\lambda} = R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$

Where, $n_1 = 1$

$$n_2 = \infty$$

$$\frac{1}{\lambda} = R\left[\frac{1}{1^2} - \frac{1}{\infty^2}\right]$$

$$\frac{1}{\lambda} = R$$

$$\lambda = \frac{1}{R} = \frac{1}{1.097 \times 10^7}\,\text{m}$$

$$= 9.116 \times 10^{-8}\text{m} \simeq 912\,\text{Å}$$

97. Calculate the minimum wavelength of the spectral line present in Balmer series of hydrogen.

Ans : **Main 2018**

The wavelength of Balmer series is given by

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$

For minimum wavelength,

$$n = \infty$$

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{\infty^2}\right)$$

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For Lyman Series :

$$\frac{1}{\lambda} = R\left(\frac{1}{1^2} - \frac{1}{n^2}\right)$$

where, $n = 2,3,4, \ldots$

For Balmer Series :

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$

where, $n = 3,4,5, \ldots$

For Paschen Series :

$$\frac{1}{\lambda} = R\left(\frac{1}{3^2} - \frac{1}{n^2}\right),$$

where, $n = 4,5,6,\ldots$

For Bracket Series :

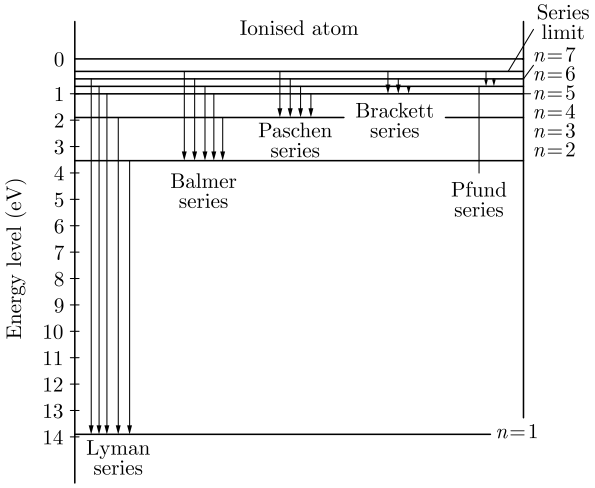
$$\frac{1}{\lambda} = R\left(\frac{1}{4^2} - \frac{1}{n^2}\right),$$

where, $n = 5,6,7, \ldots.$

For Pfund Series :

$$\frac{1}{\lambda} = R\left(\frac{1}{5^2} - \frac{1}{n^2}\right)$$

where, $n = 6,7,8,\ldots$



NUMERICAL QUESTIONS

85. In a nucleus of ${}_{92}U^{238}$, find the number of protons and the number of neutrons.

Ans : SQP 2020, 2012

Number of protons, $Z = 92$

Number of neutrons,

$$N = A - Z = 238 - 92 = 146$$

86. Obtain the approximate value of the radius of a nucleus ${}_{92}U^{238}$, R_0 is 1.2×10^{-15} m.

Ans : Main 2017

Given, $A = 238$, $R_0 = 1.2 \times 10^{-15}$ m

$$R = R_0 A^{1/3} = 1.2 \times 10^{-15}(238)^{1/3}$$
$$= 7.437 \times 10^{-15} \text{ m}$$

87. Two nuclei have mass numbers in the ratio 1 : 8. What is the ratio of their nuclear radii?

Ans : Main 2014

Radius of nucleus, $R = R_0 A^{1/3}$

Where, R_0 = constant and A = mass number

$$\frac{R_1}{R_2} = \left(\frac{A_1}{A_2}\right)^{1/3} = \left(\frac{1}{8}\right)^{1/3} = \frac{1}{2}$$
$$R_1 : R_2 = 1:2$$

88. Two stable isotopes of lithium ${}^{6}_{3}Li$ and ${}^{7}_{3}Li$ have respective abundances of 7.5% and 92.5%. These isotopes have masses 6.01512u and 7.01600u, respectively. Find the atomic mass of lithium.

Ans : Main 2018

Atomic mass of Li

$$= \text{weighted average of the isotopes}$$
$$= \frac{7.5 \times 6.01512 + 92.5 \times 7.01600}{7.5 \times 92.5}$$
$$= \frac{45.1134 + 648.98}{100} = 6.94 \text{ u}$$

89. Calculate angular momentum of an electron in the third Bohr orbit of hydrogen atom.

Ans : Main 2025

According to postulate of Bohr's model of hydrogen atom,

Angular momentum of electron in 3rd orbit,

$$mvr = \frac{nh}{2\pi}$$
$$= \frac{(3) \times (6.6 \times 10^{-34})}{2 \times 3.14} \quad (n = 3)$$
$$= 3.15 \times 10^{-34} \text{ m}$$

90. How much is the angular momentum of an electron when it is orbiting in the second Bohr orbit of hydrogen atom?

Ans : Main 2023, 2011

Angular momentum of an electron $= mvr$

As, $mvr = \frac{nh}{2\pi}$

For 2nd orbit, $n = 2$

$$mvr = \frac{2 \times 6.6 \times 10^{-34}}{2 \times 3.14}$$
$$= 2.1 \times 10^{-34} \text{ kg} - \text{m}^2/\text{s}$$

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Let e, m and v be the charge, mass and velocity of the electron respectively and r the radius of the orbit.

The positive charge on the nucleus is Ze, where Z is the atomic number (in case of hydrogen atom, $Z = 1$). As the centripetal force is provided by the electrostatic force of attraction.

We have,

$$\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{(Ze)\times e}{r^2}$$

$$mv^2 = \frac{Ze^2}{4\pi\varepsilon_0 r} \quad ...(1)$$

From the first postulate, the angular momentum of the electron is

$$mvr = n\frac{h}{2\pi} \quad ...(2)$$

where, $n = 1, 2, 3, ...$ is the principal quantum number.

From Eqs. (1) and (2), we get

$$r = n^2\frac{h^2\varepsilon_0}{\pi mZe^2}$$

This is the equation for the radii of the permitted orbits. According to this equation, $r_n \propto n^2$.

Since, $n = 1, 2, 3, ...$ it follows that the radii of the permitted orbits increase in the ratio $1 : 4 ; 9 : 16$ ... from the first orbit.

84. Give postulates of Bohr's theory. Explain hydrogen spectrum on the basis of Bohr's theory.

Ans : **SQP 2024**

Bohr combined classical and early quantum concepts and gave his theory in the form of three postulates.

These three postulates are as follows:

1. **Bohr's First Postulate** was that an electron in an atom could revolve in certain stable orbits without the emission of radiant energy, contrary to the predictions of electromagnetic theory. According to this postulate, each atom has certain definite stable states in which it can exist and each possible state has definite total energy. These are called the stationary states of the atom.
2. **Bohr's Second Postulate** states that the electron revolves around the nucleus only in those orbits for which the angular momentum is some integral multiple of $\frac{h}{2\pi}$, where h is the Plank's constant $(= 6.63 \times 10^{-34}\text{J} - \text{s})$

   Thus, the angular momentum (L) of the orbiting electron is quantised,

   i.e., $L = \frac{nh}{2\pi}$

   As, angular momentum of electron $= mvr$

   Hence, for any permitted (stationary) orbit,

   $$mvr = \frac{nh}{2\pi}$$

   where, n = any positive integer 1, 2, 3, ...

   It is also called principal quantum number.
3. **Bohr's Third Postulates** states that an electron might make a transition from one of its specified non-radiating orbits to another of lower energy, When it does so, a photon is emitted having energy equal to the energy difference between the initial and final states. The frequency of the emitted photon is given by

   $$h\nu = E_i - E_f$$

   where, E_i and E_f are the energies of the initial and final states and $E_i > E_f$.

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Hydrogen Spectrum or Line Spectra of Hydrogen Atom

Hydrogen spectrum consists of discrete bright lines in a dark background and it is specifically known as **hydrogen emission spectrum.** There is one more type of hydrogen spectrum that exists where we get dark lines on the bright background, it is known as absorption spectrum.

Blamer found an empirical formula by the observation of a small part of this spectrum and it is represented by.

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$

where, $n = 3, 4, 5, ...$

and, $R =$ is a constant called Rydberg constant and its value is $1.097 \times 10^7\text{m}^{-1}$

So, $\frac{1}{\lambda} = 1.522 \times 10^6\text{m}^{-1}$

$= 656.3\,\text{nm}$ for $n = 3$

Other series of spectra for hydrogen were subsequently discovered and known by the name of their discoverers. The lines of Balmer series are found in the visible part of the spectrum. Other series were found in the invisible parts of the spectrum.

e.g. Lyman series in the ultraviolet region and Paschen, Brackett and Pfund in the infrared region.

The wavelength of line in these series can be expressed by the following formulae.

$$\frac{1}{\lambda} = \frac{R}{4}$$

$$\lambda = \frac{4}{R} = \frac{4}{1.097 \times 10^7}$$

$$= 3.646 \times 10^{-7}\,\text{m}$$

$$= 3646\,\text{Å}$$

This lies in the ultraviolet region.

98. What is the ratio of radii of the orbits corresponding to first excited state and ground state, in a hydrogen atom?

Ans : **Main 2021**

For first excited states $n = 2$

Ground state occurs for $n = 1$

Hence, $r_n = r_0 n^2$

Since, $r \propto n^2$ $[r_0 = 0.53]$

$$\frac{r_1}{r_2} = \left(\frac{n_1}{n_2}\right)^2$$

$$= \left(\frac{2}{1}\right)^2$$

$$r_1 : r_2 = 4 : 1$$

Where, r_1 and r_2 are radii corresponding to first excited state and ground state of the atom.

99. In the Rutherford scattering experiment, the distance of closest approach for an α-particle is d_0. If α-particle is replaced by a proton, then how much kinetic energy in comparison to α-particle will be required to have the same distance of closest approach d_0?

Ans : **Comp 2021**

Distance of closest approach

$$d_0 = \frac{2kZe^2}{K_X} \quad \text{Where, } k = \frac{1}{4\pi\varepsilon_0}$$

Since, for given distance of closest approach, kinetic energy $\propto$ Z (atomic number)

$$\frac{K_{\text{proton}}}{K_\alpha} = \frac{Z_{\text{proton}}}{Z_\alpha}$$

$$= \frac{1}{2}$$

K_{proton} : $K_\alpha = 1 : 2$

100. Find the ratio of energies of photons produced due to transition of an electron of hydrogen atom from its

(i) second permitted energy level to the first permitted level and

(ii) the highest permitted energy level to the first permitted level.

Ans : **SQP 2021**

(i) Since, the second permitted energy level to the first level $= E_2 - E_1$ = energy of photon released.

$$(-3.4eV) - (-13.6eV) = 10.2eV$$

(ii) The highest permitted energy level to the first permitted level

$$E_\infty - E_1 = 0 - (-13.6)$$

$$= 13.6eV$$

Hence, Ratio of energies of photon

$$= \frac{10.2}{13.6} = \frac{3}{4} = 3 : 4$$

101. The energy on the first Bohr's orbit is – 27.2 eV. What will be the energy in the third orbit?

Ans : **Main 2024, 2005**

According to Bohr's postulate,

Energy of nth orbit,

$$E \propto \frac{1}{n^2}$$

So, $E_1 \propto \frac{1}{n_1^2}$

and $E_2 \propto \frac{1}{n_2^2}$

$$\frac{E_1}{E_2} = \frac{n_2^2}{n_1^2}$$

As, $n_1 = 1,\ n_2 = 3,\ E_1 = -27.2\,\text{eV}$

So, $E_2 = E_1 \frac{n_1^2}{n_2^2} = -27.2\,\text{eV} \times \frac{1^2}{3^2}$

$$= \frac{-27.2}{9} = -3.02\,\text{eV}$$

102. The radius of the innermost electron orbit of a hydrogen atom is 5.3×10^{-11}m. Calculate its radius in $n = 3$ orbit.

Ans : **SQP 2011**

Given,

Bohr's radius, $r_0 = 5.3 \times 10^{-11}\,\text{m}$

$n = 3$

Total energy of an electron in first excited state

$$= -3.4\,\text{eV}$$

Radius of orbit is given by,

$$r_n = n^2 r_0$$

For $n = 3$

$$r_3 = (3)^2 \times 5.3 \times 10^{-11}$$

$$= 47.7 \times 10^{-11}$$

$$= 4.77 \times 10^{-10}\text{m}$$

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The size of nucleus can be obtained by finding the distance of closest approach, which is given by

$$r_0 = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2Ze^2}{(KE)}$$

Where, $+Ze$ = charge in nucleus

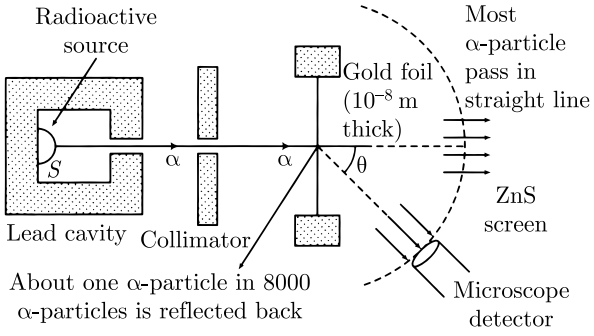
$+2e$ = charge on α-particle

$\frac{1}{4\pi\varepsilon_0} = K =$ coulomb constant.

81. Describe Rutherford's model of atom developed on the basis of his alpha particle scattering experiment.

Ans : **SQP 2020, 2016**

This experiment was suggested by Rutherford in 1911 as given in the figure below.



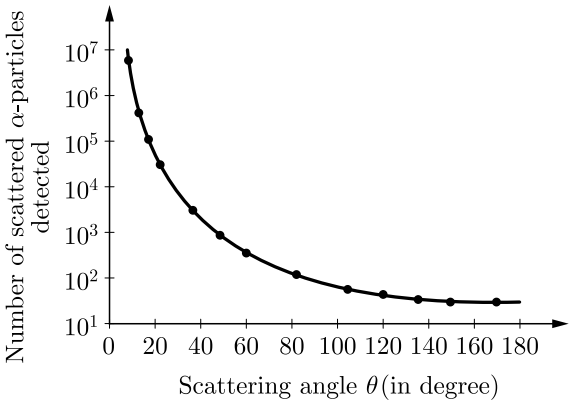
In this experiment, H Geiger and E Marsden took $^{214}_{83}$Bi as a source for α-particles. A collimated beam of α-particles of energy 5.5 MeV was allowed to fall on 2.1×10^{-7}m thick gold foil. The α-particles were observed through a rotatable detector consisting of a zinc sulphide screen and microscope and it was found that α-particles got scattered. These scattered α-particles produced scintillations on the zinc sulphide screen. Now, these scintillation were counted at different angles from the direction of incident beam.

Observations

Rutherford made the following observations from his experiment that are given below

1. Most of the α-particles passed through the gold foil without any appreciable deflection.
2. Only about 0.14% of the incident α-particles scattered by more than 1°.
3. About one α-particle in every 8000 α -particles deflected by more than 90°.

   The total number of α-particles (N) scattered through an angle (θ) is as shown in the below figure:



4. The number of α-particles scattered per unit area $N(\theta)$ at scattering angle θ varies inversely as $\frac{\sin^4\theta}{2}$.

$$N(\theta) \propto \frac{1}{\frac{\sin^4\theta}{2}}$$

5. The force between α-particles and nucleus is given by,

$$F = \frac{1}{4\pi\varepsilon_0}\cdot\frac{(2e)(Ze)}{r^2}$$

Where, r is the distance between the α-particles and the nucleus. This force is directed along the line joining the α-particle and the nucleus. The magnitude and direction of this force on α -particle continuously changes as it approaches the nucleus and recedes away from it.

82. What is the energy level diagram for an atom? Calculate the energies of the various energy levels of a hydrogen atom and draw and energy level diagram for it.

Ans : **Main 2025**

Energy Level Diagram : It is a diagram in which the energies of the different stationary states of an atom are represented by parallel horizontal lines, drawn according to some suitable energy scale.

Energy Levels of Hydrogen : From Bohr's theory, the total energy of an electron in n^{th} orbit is given by,

$$E_n = -\frac{2\pi^2 mk^2 Z^2 e^4}{n^2 h^2}$$

For hydrogen $Z = 1$, therefore,

$$E_n = -\frac{2\pi^2 mk^2 e^4}{h^2}\cdot\frac{1}{n^2}$$

Energy of the electron in the first orbit $(n = 1)$ is given by,

$$E_1 = -\frac{2\times(3.14)^2\times 9.11\times10^{-31}\times(9\times10^9)^2\times(1.6\times10^{-19})^4}{(6.63\times10^{-34})^2}\cdot\frac{1}{1^2}$$

$$= -21.76\times10^{-19}\text{ J}$$

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(ii) Maximum energy of photon is given by

$$\Delta E = E_\infty - E_1$$
$$= 0 - (-13.6) = 13.6\,\text{eV}$$

108. In the ground state of hydrogen atom, its Bohr radius is given as 5.3×10^{-11}m. The atom is excited such that the radius becomes 21.2×10^{-11}m. Find :

1. The value of the principal quantum number.
2. Total energy of the atom in this excited state.

Ans : **Main 2017**

1. Given, $r_1 = 5.3 \times 10^{-11}$m

$$r_2 = 21.2 \times 10^{-11}\text{m}$$
$$n_1 = 1$$
$$r \propto n^2$$
$$\frac{r_1}{r_2} = \frac{n_1^2}{n_2^2}$$
$$n_1 = 1$$
$$\frac{1}{n_2^2} = \frac{5.3 \times 10^{-11}}{21.2 \times 10^{-11}}$$
$$n_2^2 = 4$$
$$n_2 = 2$$

2. $$E = \frac{-13.6}{n^2}$$
$$= \frac{-13.6}{4} = -3.4\,\text{eV}$$

109. Energy levels of H-atom are given by $E_n = \frac{-13.6}{n^2}$ eV Where, n = principal quantum number to calculate the wavelength of electromagnetic radiation emitted by hydrogen atom resulting from the transition $n = 2$to $n = 1$.

Ans : **Main 2024, 2012**

$$E_n = \frac{-13.6}{2^2}\,\text{eV}$$

So, for $n = 2$, $E_n = \frac{-13.6}{2^2} = -3.4\,\text{eV}$

and for $n = 1$, $E_n = \frac{-13.6}{1^2} = -13.6\,\text{eV}$

So, $E = E_2 - E_1$

$$= \left[-3.4 - (-13.6)\right]\text{eV}$$
$$\Delta E = \frac{hc}{\lambda} = 10.2\,\text{eV}$$

where, λ = wavelength of emitted

Electromagnetic radiation

$$\lambda = \frac{hc}{10.2} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{10.2 \times 1.6 \times 10^{-19}}$$
$$= 1.213 \times 10^{-7}\,\text{m} = 1213\,\text{Å}$$

110. Wavelength of 1st line (H_α) of Balmer series of hydrogen is 656.3 nm. Find the wavelength of its second line (H_β).

Ans : **Main 2009**

$$\frac{1}{\lambda} = Z^2 R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

For Balmer series, first line (H_α)

$$n_1 = 2,\ n_2 = 3,\ \lambda = 656.3\,\text{nm}$$
$$\frac{1}{656.3 \times 10^{-19}\,\text{m}} = R\left(\frac{1}{2^2} - \frac{1}{3^2}\right)$$
$$= R\left(\frac{1}{4} - \frac{1}{9}\right)$$
$$R = 1.09 \times 10^7$$

For Balmer series 2nd line (H_β)

$$n = 2,\ n_2 = 4 \qquad \text{[given]}$$
$$\frac{1}{\lambda} = R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$
$$\frac{1}{\lambda} = 1.09 \times 10^7\left(\frac{1}{4} - \frac{1}{16}\right)$$
$$\lambda = 4.89 \times 10^{-7}\,\text{m}$$

111. Boron has two stable isotopes ${}^{10}_{5}\text{B}$ and ${}^{11}_{5}\text{B}$. Their respective masses are 10.01294u and 11.00931u and the atomic mass of boron is 10.811u. Find the abundances of ${}^{10}_{5}\text{B}$ and ${}^{11}_{5}\text{B}$.

Ans : **Main 2020, 2017**

Suppose x and y are the abundances of ${}^{10}_{5}\text{B}$ and ${}^{11}_{5}\text{B}$ respectively.

Atomic mass of boron

$$= \text{weighted average of isotopes}$$
$$= \frac{x \times 10.01294 + y \times 11.00931}{100}$$
$$108.11 = \frac{x \times 10.01294 + (100 - x) \times 11.00931}{100}$$
$$[y = (100 - x)]$$
$$108.11 = 10.01294x + 1100.931 - 11.00931x$$
$$0.99637x = 19.831$$
$$x = 19.90$$
$$y = (100 - x)$$
$$= 80.1$$
$$x = 19.90\%$$
$$y = 80.1\%$$

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$$12.3 = -\frac{13.6}{n^2} - \left(-\frac{13.6}{1^2}\right)$$
$$12.3 = 13.6\left[1 - \frac{1}{n^2}\right]$$
$$\frac{12.3}{13.6} = 1 - \frac{1}{n^2}$$
$$n^2 = 10$$
$$n = 3$$

That is the hydrogen atom would be excited upto second excited state.

For Lyman Series

$$\frac{1}{\lambda} = R\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right]$$
$$\frac{1}{\lambda} = 1.097 \times 10^7\left[\frac{1}{1} - \frac{1}{9}\right]$$
$$\frac{1}{\lambda} = 1.097 \times 10^7 \times \frac{8}{9}$$
$$\lambda = \frac{9}{8 \times 1.097 \times 10^7}$$
$$= 1.025 \times 10^{-7}$$
$$= 102.5\,\text{nm}$$

For Balmer Series

$$\frac{1}{\lambda} = 1.097 \times 10^7\left[\frac{1}{4} - \frac{1}{16}\right]$$
$$\frac{1}{\lambda} = 1.097 \times 10^7 \times \frac{3}{16}$$
$$\lambda = 4.86 \times 10^{-7}\,\text{m} = 486\,\text{nm}$$

134. An electron in a hydrogen atom, moves form n_1 to n_2 state. If time-period of the electron in the initial state is eight times that of final state,What is the possible values of n_1 and n_2?

Ans : **Comp 2014**

Initial energy level $= n_1$

Final energy level $= n_2$

Initial time-period, $T_1 = 8\,T_2$

(where, T_2 is final time-period)

We know from the Bohr's atomic model that radius of n^{th} orbit,

$$r_n = \frac{\varepsilon_0 n^2 h^2}{\pi m e^2} \propto n^2$$

Therefore, $$\frac{r_1}{r_2} = \left(\frac{n_1}{n_2}\right)^2 \quad ...(1)$$

and velocity of electron in n^{th} orbit,

$$v_n = \frac{e^2}{2\varepsilon_0 hn} \propto \frac{1}{n}$$

Therefore, $$\frac{v_1}{v_2} = \frac{n_2}{n_1} \quad ...(2)$$

We also know that time-period of electron in n^{th} orbit,

$$T_n = \frac{2\pi r_n}{v_n} \propto \frac{r_n}{v_n}$$

Therefore, $$\frac{T_1}{T_2} = \frac{r_1}{r_2} \times \frac{v_2}{v_1}$$
$$= \left(\frac{n_1}{n_2}\right)^2 \times \frac{n_1}{n_2}$$
$$= \left(\frac{n_1}{n_2}\right)^3$$

or $$\frac{8\,T_2}{T_2} = \left(\frac{n_1}{n_2}\right)^3$$

or $$\frac{n_1}{n_2} = 2$$

Thus possible value of n_1 and n_2 are $n_1 = 4$ and $n_2 = 2$.

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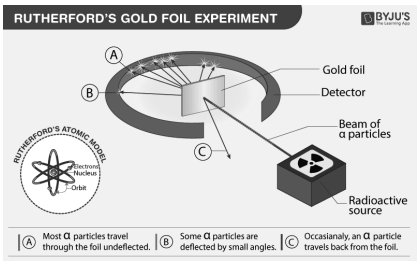
CASE BASED QUESTIONS

135. Rutherford's atomic model was a reasonably good model of structure of atom based on the famous α-particle scattering experiment. However, it was subsequently modified by Neils Bohr and later on, by others. The resulting improvements in the understanding of atomic structure have greatly contributed to further scientific advancement. There are many other similar examples in scientific field when original contributors happily accept modifications in their ideas.



1. Write two major drawbacks of Rutherford's atomic model ?
2. How were these drawbacks overcome in Neils Bohr Model ?

Ans :

1. Drawbacks :
   (a) An accelerated electron must limit radiation and should fall into the nucleus.
   (b) An atom should emit continuous spectrum which is contrary to experimental results.

We also know that radius of $_{100}Fe^{257}$ atom,

$$r_n = \frac{n^2 r_0}{Z}$$

or $$mr_0 = \frac{n^2 r_0}{Z}$$

or $$m = \frac{n^2}{Z}$$

$$= \frac{(5)^2}{100}$$

$$= \frac{25}{100} = \frac{1}{4}$$

117. In a hydrogen atom, when an electron jumps from second orbit to first orbit, What is the wavelength of spectral line emitted by hydrogen atom?

Ans : **Comp 2018**

Initial energy level, $n_1 = 2$

Final energy level, $n_2 = 1$

Change in energy,

$$\Delta E = -13.6\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

$$= -13.6\left[\frac{1}{(2)^2} - \frac{1}{(1)^2}\right]$$

$$= -13.6\left[\frac{-3}{4}\right]$$

$$= 10.2\,\text{eV}$$

We also know that wavelength of emitted spectral line,

$$\lambda = \frac{12375}{\Delta E}$$

$$= \frac{12375}{10.2} = 1213\,\text{Å}$$

118. An electron revolves around the nucleus of hydrogen atom in a circular orbit of radius 5×10^{-11} m. Calculate

(i) intensity of electric field of the nucleus of the position of the electron.

(ii) electrostatic potential energy of the hydrogen nucleus and electron system.

Ans : **Main 2010**

(i) Radius $r = 5 \times 10^{-11}$ m, charge $q = +e$
So, electric field

$$E = \frac{q}{4\pi\varepsilon_0 r^2}$$

$$= 9 \times 10^9 \times \frac{1.6 \times 10^{-9}}{(5 \times 10^{-11})^2}$$

$$\left[\text{as } \frac{1}{4\pi\varepsilon_0} = 9 \times 10^9\right]$$

$$= 5.76 \times 10^{11}\,\text{NC}^{-1}$$

(ii) As potential energy of system is given by

$$U = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r}$$

$$= \frac{9 \times 10^9 \times (1.6 \times 10^{-19}) \times (-1.6 \times 10^{-19})}{5 \times 10^{-11}}$$

$$= -4.608 \times 10^{-18}\,\text{J}$$

119. A hydrogen atom initially in its ground absorbs a photon and is in the excited state with energy 12.5 eV. Calculate the longest wavelength of the radiation emitted and identify the series to which it belongs.

[Take, Rydberg constant $R = 1.1 \times 10^7 \text{m}^{-1}$]

Ans : **Comp 2010**

Let n_i and n_f are the quantum numbers of initial and final states, then we have

$$\frac{1}{\lambda_{\max}} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

The energy of the incident photon $= 12.5\,\text{eV}$

Energy of ground state $= -13.6\,\text{eV}$

Hence, Energy after absorption of photon can be $-1.1\,\text{eV}$

This means that electron can go to the excited state $n_i = 3$.

It emits photon of maximum wavelength on going to $n_f = 2$, therefore,

$$\frac{1}{\lambda_{\max}} = \left(\frac{1}{2^2} - \frac{1}{3^2}\right)R$$

$$\lambda_{\max} = \frac{36}{5R} = \frac{36}{5 \times 1.1 \times 10^7}$$

$$= 6.555 \times 10^{-7}\text{m}$$

$$= 6555\text{Å}$$

It belongs to balmer series.

120. Use Bohr model of hydrogen atom to calculate the speed of the electron in the first excited state.

Ans : **SQP 2016**

Bohr's quantum condition is

$$mvr = \frac{nh}{2\pi}$$

$$v = \frac{nh}{2\pi mr}$$

and $$r = \frac{1}{k}\frac{n^2h^2}{4\pi^2 me^2}$$

So, $$v = k\frac{2\pi e^2}{nh}$$

$$= \frac{1}{4\pi\varepsilon_0} \cdot \frac{2\pi e^2}{nh} = \frac{e^2}{2\varepsilon_0 h} \cdot \frac{1}{n}$$

$$v = \frac{e^2}{2\varepsilon_0 h} \cdot \frac{1}{n}$$

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112. Calculate the shortest wavelength in the Balmer series of hydrogen atom. In which region (infrared visible, ultraviolet) of hydrogen spectrum does this wavelength lie?

Ans : **Comp 2018, 2011**

For Balmer series,

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n_2^2}\right),\ n_2 = 3,\ 4,\ 5,\ \ldots$$

For shortest wavelength in Balmer series, the spectral series is given by,

$$n_1 = 2,\ n_2 = \infty$$

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{\infty^2}\right)$$

$$\frac{1}{\lambda} = R \times \frac{1}{4}$$

$$\frac{1}{\lambda} = \frac{R}{4}$$

$$\lambda = \frac{4}{R} = \frac{4}{1.097 \times 10^7}$$

$$[\because\ R = 1.097 \times 10^7\, m^{-1}]$$

$$= 3.64 \times 10^{-7}\ \text{m}$$

The lines of Balmer series are found in the visible part of the spectrum.

113. What is H_α line in the emission spectrum of hydrogen atom obtained? Calculate the frequency of the photon emitted during this transition.

Ans : **SQP 2012**

The line with the longer wavelength of the Balmer series is called H_α.

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$

Where, λ = wavelength

$R = 1.097 \times 10^7 \text{m}^{-1}$ (Rydberg constant)

When the electron jumps from the orbit with $n = 3$ to $n = 2$.

We have, $\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{3^2}\right)$

$$\frac{1}{\lambda} = \frac{5}{36}R$$

The frequency of photon emitted is given by,

$$v = \frac{c}{\lambda} = c \times \frac{5}{36}R$$

$$= 3 \times 10^8 \times \frac{5}{36} \times 1.097 \times 10^7 \text{Hz}$$

$$= 4.57 \times 10^{14}\ \text{Hz}$$

114. α-particles having KE of 1.8 MeV each are incident on a thin gold foil from a large distance. Applying the principle of conservation of energy, find the distance of closes approach of the α -particle from the gold nucleus. (Atomic number of gold = 79)

Ans : **Main 2009**

Let the distance of closest approach of the α -particle be r_0.

So, by principle of conservation of energy,

Kinetic energy KE = Potential energy PE

$$\text{KE} = U = \frac{1}{4\pi\varepsilon_0}\frac{Ze(2e)}{r_0}$$

$$r_0 = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2Ze^2}{\text{KE}}$$

$$= \frac{9 \times 10^9 \times 2 \times 79 \times (1.6 \times 10^{-19})}{1.8 \times 1.6 \times 10^{-13}}$$

$$= 1.264 \times 10^{-13}\ \text{m}$$

where, $+Ze$ = charge in nucleus

$+2e$ = charge on α-particle

$\frac{1}{4\pi\varepsilon_0} = K$ = coulomb constant

115. Calculate the shortest wavelength of the spectral lines emitted in balmer series.

[Given Rydberg constant, $R = 10^7\, m^{-1}$]

Ans : **SQP 2025**

For hydrogen spectra,

$$\frac{1}{\lambda} = R\left(\frac{1}{n^2} - \frac{1}{m^2}\right)$$

Where, n = orbit on which electron jump;

m = orbit from which electron jump.

For balmer series. $n = 2$

But for shortest wavelength,

$$n = \infty$$

Hence, $\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{\infty^2}\right) = \frac{R}{4}$

$$\lambda = \frac{4}{R} = 4 \times 10^{-7}\text{m}$$

116. If the atom ${}_{100}\text{Fm}^{257}$ follows the Bohr's atomic model and radius of ${}_{100}\text{Fm}^{257}$ is m times the Bohr radius, what is the value of m ?

Ans : **Main 2019, 2015**

Atom = ${}_{100}\text{Fm}^{257}$

Radius of atoms, $r_n = mr_0$

(Where, r_0 is Bohr radius)

Principal quantum no. of ${}_{100}\text{Fm}^{257}$ atom,

$$n = 5$$

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124. The first member of Balmer's series of hydrogen has a wavelength of 6563 Å. What is the wavelength of its second member?

Ans : SQP 2010

Wavelength of first member, $\lambda_1 = 6563$ Å

In Balmer series, first wavelength corresponds to $n_1 = 3$ and second wavelength corresponds to $n_2 = 4$.

We also know that relation for the wavelength of first member in Balmer series λ_1 is,

$$\frac{1}{\lambda_1} = R_H\left[\frac{1}{(2)^2} - \frac{1}{(n_1)^2}\right]$$

$$\frac{1}{6563} = R_H\left[\frac{1}{(2)^2} - \frac{1}{(3)^2}\right]$$

$$= R_H\left[\frac{1}{4} - \frac{1}{9}\right] = \frac{5R_H}{36} \quad ...(1)$$

Similarly, relation for the wavelength of second member in Balmer series λ_2 is,

$$\frac{1}{\lambda_2} = R_H\left[\frac{1}{(2)^2} - \frac{1}{(n_2)^2}\right]$$

$$= \frac{1}{\lambda_2} \times R_H\left[\frac{1}{(2)^2} - \frac{1}{(4)^2}\right]$$

$$= R_H\left[\frac{1}{4} - \frac{1}{16}\right] = \frac{3R_H}{16} \quad ...(2)$$

Dividing equation (1) and (2),

$$\frac{\frac{1}{6563}}{\frac{1}{\lambda_2}} = \frac{\frac{5R_H}{36}}{\frac{3R_H}{16}}$$

$$\frac{\lambda_2}{6563} = \frac{5}{36} \times \frac{16}{3} = \frac{80}{108}$$

$$\lambda_2 = \frac{6563 \times 80}{108} = 4861 \text{ Å}$$

125. The ground state energy of hydrogen atom is -13.6 eV. If an electron makes a transition from an energy level -0.85 eV to 3.4 eV, Calculate the wavelength of the spectral line emitted. To which series of hydrogen spectrum does this wavelength belong?

Ans : SQP 2013

As we know that, $E_n = \frac{-13.6}{n^2}$ eV ...(1)

For, $n = 1,\ E_1 = -13.6$ eV

When electron undergoes transition from,

$$E_A = 0.85 \text{ eV to } E_B = -3.4 \text{ eV}$$

Then, from equation (1),

$$-0.85 = \frac{-13.6}{n_A^2}$$

$$n_A = 4$$

Similarly, $$-3.4 = \frac{-13.6}{n_B^2}$$

$$n_B = 2$$

Hence, electron transits from $n = 4$ to $n = 2$. It corresponds to Balmer series.

We know, $$\frac{1}{\lambda} = R\left(\frac{1}{n_B^2} - \frac{1}{n_A^2}\right)$$

Here, $n_A = 4,\ n_B = 2,$

$$R = 1.097 \times 10^7 \text{ m}^{-1}$$

Then, $$\frac{1}{\lambda} = 1.097 \times 10^7\left(\frac{1}{2^2} - \frac{1}{4^2}\right)$$

$$\lambda = 4862 \text{ Å}$$

126. The electron in a given Bohr orbit has a total energy of -1.5 eV. Calculate its

(i) kinetic energy

(ii) potential energy

(iii) wavelength of radiation emitted, when this electron makes a transition to the ground state.

[Given, energy in the ground state $= -13.6$ eV and Rydberg's constant $= 1.09 \times 10^7$ m^{-1}

Ans : Comp 2020

(i) The kinetic energy (K_K) of the electron in an orbit is equal to negative of its total energy (E).

$$E_K = -E = -(-1.5) = 1.5 \text{ eV}$$

(ii) The potential energy (U) of the electron in an orbit is equal to twice its total energy (E)

i.e., $$U = 2E = -1.5 \times 2 = -3 \text{ eV}$$

(iii) As, a result of transition of electron from excited state of ground state.

Energy of radiation $= -1.5 - (-13.6)$

(Since, Ground state energy of H-atom $= -13.6$ eV)

$$E = h\nu = h\frac{c}{\lambda}$$

$$\frac{hc}{\lambda} = 12.1 \text{ eV} = \text{energy of radiation}$$

Hence, $$\frac{1}{\lambda} = \frac{12.1 \times 1.6 \times 10^{-19}}{6.62 \times 10^{-34} \times 3 \times 10^8}$$

$$\lambda = 1.025 \times 10^{-7} \text{ m} = 1025 \text{ Å}$$

127. The value of ground state energy of hydrogen atom is -13.6 eV.

1. Find the energy required to move an electron from the ground state to the first excited state of the atom.
2. Determine (a) the kinetic energy and (b) orbital radius in the first excited state of the atom.

[Given, the value of bohr's radius $= 0.53$ Å]

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(v) What conclusion was drawn by Rutherford based on Geiger-Marsden's experiment on scattering of α-particles?

Ans :

(i) The gold nucleus is heavy and so it can produce a 'large' deflection in the path of α -particle. Secondly, gold can be beaten into extremely 'thin' foils.

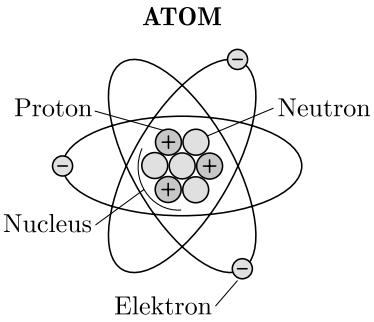
(ii) Electron is very light compared to α-particle. Hence, due to conservation of momentum, it cannot scatter the α-particle at large angles.

(iii) This was to ensure that an α-particle should be deflected by a 'single' collision.

(iv) Most of the inner part of atom is hollow and the positive charge of the atom is concentrated in a very small space (nucleus).

(v) The positive charge of an atom was confined to a tiny space at the centre called nucleus of the atom.

138. Everything around us which has mass and occupies space is matter. It cannot be broken down further using any chemical means because it is the basic building block of an element. Every state of matter solid, liquid, gas, and plasma is composed of either atom either it is neutral (unionized), or ionized atoms. An atom is made up of three particles known as protons, neutrons, and electrons. And these particles are also made up from sub-particles. Among these three particles, protons have a positive charge while electrons carry a negative charge and the third particle neutrons have no electrical charge. And the charge of atoms depends on the number of protons and electrons, i.e. an atom is electrically neutral if the number of protons and electrons are equal. If an atom has more or fewer electrons than protons, then it has an overall negative or positive charge, respectively. These atoms are extremely small or you can say their typical sizes are around 100 picometers. So the dense region consisting of protons and neutrons at the center of an atom is known as the atomic nucleus of an atom. Every atom is composed of such nucleus and some elections will be surrounding it. Studying these atoms and Nuclei will help us to have a thorough understanding of matter. Studying about the nucleus and its reactions will help us to understand more about nuclear energy, which is a very useful renewable energy. That's why it is very important to study about Atoms and Nuclei.



1. What is the basic unit of matter?
2. Which particle is responsible for the ionization of the atom?
3 Which is the most dense part of an atom?

Ans :

1. Atom.
2. Electron.
3. The region at the center of atom containing neutrons and protons.

139. Rutherford was the pioneer who postulated and established the existence of the atomic nucleus. At Rutherford's suggestion, Geiger and Marsden performed their classic experiment on the scattering of α-particles from thin gold foils. Their experiments revealed that the distance of closest approach to a gold nucleus of an α-particle of kinetic energy 5.5 MeV is about 4.0×10^{-14}m. The scattering of α -particle by the gold sheet could be understood by Rutherford by assuming that the coulomb repulsive force was solely responsible for scattering. Since the positive charge is confined to the nucleus, the actual size of the nucleus has to be less than 4.0×10^{-14}m . If we use α-particles of higher energies than 5.5 MeV, the distance of closest approach to the gold nucleus will be smaller and at some point the scattering will begin to be affected by the short range nuclear forces, and differ from Rutherford's calculations. Rutherford's calculations are based on pure coulomb repulsion between the positive charges of the α particle and the gold nucleus. From the distance at which deviations set in, nuclear sizes can be inferred. By performing scattering experiments in which fast electrons, instead of α particles, are projectiles that bombard targets made up of various elements, the sizes of nuclei of various elements have been accurately measured. It has been found that a nucleus of mass number A has a radius $R = R_0 A^{\frac{1}{3}}$, where $R_0 = 1.2 \times 10^{-15}$m. This means the volume of the nucleus, which is proportional to R^3 is proportional to A. Thus the density of nucleus is a constant, independent of A, for all nuclei. Different nuclei are likes drop of liquid of constant density. The density of nuclear matter

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Energy required to move an electron

$$= E_2 - E_1 = -3.4 - (-13.6)$$

$$= -3.4 + 13.6 = 10.2\,\text{eV}$$

(ii) (a) Kinetic energy $=-$ (Total energy of the electron in first excited state).

$$= -(-3.41) = 3.4\,\text{eV}$$

(b) Orbital radius in the state $\propto n^2$

[For first excited state, $n = 2$]

$$= n \times 0.53 = 2.12\,\text{Å}$$

131. A 12.5 eV electron beam is used to bombard gaseous hydrogen at room temperature. Upto which energy level the hydrogen atoms would be excited ? Calculate the wavelengths of the first members of Lyman and first member of Balmer series.

Ans : **Main 2016**

The energy of gaseous hydrogen at room temperature are,

$$E_1 = -13.6\,\text{eV}$$

$$E_2 = -3.4\,\text{eV}$$

$$E_3 = -1.51\,\text{eV}$$

$$E_4 = -0.85\,\text{eV}$$

$$E_3 - E_1 = -1.51 - (-13.6)$$

$$= 12.09\,\text{eV}$$

and $$E_4 - E_1 = -0.85 - (-13.6)$$

$$= 12.75\,\text{eV}$$

As both the values does not match the given value, but it is nearest to $E_4 - E_1$.

Hence, upto E_4 energy level the hydrogen atoms would be excited.

Lyman Series

$$\frac{1}{\lambda} = R\left[\frac{1}{1^2} - \frac{1}{n^2}\right]$$

For first member, $n = 2$

Hence, $$\frac{1}{\lambda_1} = R\left[\frac{1}{1^2} - \frac{1}{2^2}\right]$$

$$= 1.097 \times 10^7\left[\frac{4-4}{4}\right]$$

$$\lambda_1 = 1.215 \times 10^{-7}\text{m}$$

Balmer Series

$$\frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{n^2}\right]$$

For first member, $n = 3$

Hence, $$\frac{1}{\lambda_1} = R\left[\frac{1}{2^2} - \frac{1}{3^2}\right]$$

$$= 1.097 \times 10^7\left[\frac{1}{4} - \frac{1}{9}\right]$$

$$\lambda_1 = 6.56 \times 10^{-7}\,\text{m}$$

132. The electron in a given Bohr orbit has a total energy of -1.5 eV. Calculate its

1. Kinetic energy
2. Potential energy
3. Wavelength of radiation emitted, when this electron makes a transition to the ground state.

(Given, energy in the ground state $=-13.6$ eV and Rydberg's constant $= 1.09 \times 10^7\,\text{m}^{-1}$)

Ans : **Main 2017**

1. The kinetic energy E_K of the electron in an orbit is equal to negative of its total energy E

$$E_K = -E$$

$$= -(-1.5) = 1.5\,\text{eV}$$

2. The potential energy U of the electron in an orbit is equal to twice its total energy E.

i.e., $$U = 2E$$

$$= -1.5 \times 2 = -3\,\text{eV}$$

3. As, a result of transition of electron from excited state of ground state.

Energy of radiation $= -1.5 - (-13.6)$

Hence, Ground state energy of H-atom $=-13.6$ eV

$$E = h\nu = h\frac{v}{\lambda}$$

$$\frac{hc}{\lambda} = 12.1\,\text{eV} = \text{energy of radiation}$$

Hence, $$\frac{1}{\lambda} = \frac{12.1 \times 1.6 \times 10^{-19}}{6.62 \times 10^{-34} \times 3 \times 10^8}$$

$$\lambda = 1.025 \times 10^{-7}\text{m} = 1025\,\text{Å}$$

133. A 12.3 eV electron beam is used to bombard gaseous hydrogen at room temperature. Upto which energy level the hydrogen atoms would be excited? Calculate the wavelengths of the second member of Lyman series and second member of Balmer series.

Ans : **SQP 2010, 2007**

The energy of electron in the nth orbit of hydrogen atom is,

$$E_n = -\frac{13.6}{n^2}\,\text{eV}$$

When the incident beam of energy 12.3 eV is absorbed by hydrogen atom. Let the electron jump from $n = 1$ to $n = n$ level.

$$E = E_n - E_1$$

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$$= \frac{(1.6 \times 10^{-19})^2}{2 \times 8.85 \times 10^{-12} \times 6.63 \times 10^{-34}}\left(\frac{1}{n}\right)$$

$$= \frac{2.18 \times 10^6}{n} \text{m/s}$$

For $n = 2, v_2 = \frac{2.18 \times 10^6}{2} = 1.09 \times 10^6 \text{m/s}$

For $n = 3, v_3 = \frac{2.18 \times 10^6}{3} = 7.27 \times 10^5 \text{m/s}$

Obviously the speed of electron goes on decreasing with increasing n.

121. In a Geiger-marsdon experiment, calculate the difference of closest approach to the nucleus of $Z = 80$ when an α-particles of 8 MeV energy impinges on it before it comes to momentarily rest and reverses its direction. How will the distance of closest approach be affected when the kinetic energy of the α-particle is doubled?

Ans : **Main 2021**

Given, $Z = 80,\ E_K = K = 8\,\text{MeV}$

$$= 8 \times 10^6 \times 1.6 \times 10^{-19}\text{J}$$

Energy conservation law,

$$K = \frac{(Ze)(2e)}{4\pi\varepsilon_0 r_0}$$

Where, r_0 = distance of closest approach.

$$r_0 = \frac{2Ze^2}{4\pi\varepsilon_0(K)}$$

$$r_0 = \frac{9 \times 10^9 \times 2 \times 80 \times (1.6 \times 10^{-19})^2}{8 \times 10^6 \times 1.6 \times 10^{-19}}$$

$$r_0 = 2.88 \times 10^{-14}\text{m}$$

$$r_0 = \frac{1}{K}$$

If E_K gets doubled distance of closest approach reduces to half.

122. The ground state energy of hydrogen is -13.6 eV. What is the kinetic and potential energies of the electron in this state?

Ans : **SQP 2021, 2010**

Kinetic energy, $E_K = \frac{1}{2}mv^2 = \frac{1}{4\pi\varepsilon_0} \cdot \frac{e^2}{2r}$ ...(1)

Potential energy, $U = -\frac{1}{4\pi\varepsilon_0} \cdot \frac{e^2}{r}$ ...(2)

Total energy, $E = E_K + U = -\frac{1}{4\pi\varepsilon_0}\frac{e^2}{2r}$ ...(3)

Comparing equations (1), (2), (3), we have

$$E_K = -E \text{ and } U = 2E$$

Given, $E = -13.6\,\text{eV}$

For ground state $n = 1$

Hence, kinetic energy,

$$E_K = 13.6\,\text{eV}$$

Potential energy, $U = 2 \times (-13.6\,\text{eV})$

$$= -27.2\,\text{eV}$$

For second excited state, $n = 3$

$$E_K = -E$$

$$= \frac{+13.6}{9}\text{eV}$$

$$= 1.51\,\text{eV}$$

and $U = 2E = \frac{2 \times (-13.6\,\text{eV})}{9}$

$$= -3.02\,\text{eV}$$

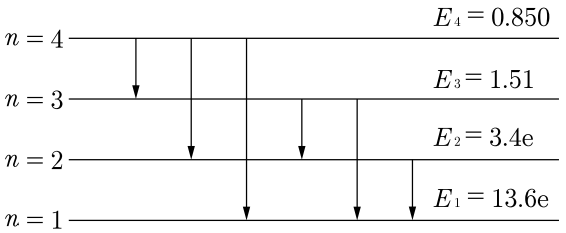
123. The ionisation potential of hydrogen atom is 13.6 eV. Draw the energy level diagram showing four levels. Calculate

(i) the energy of the photon emitted when an electron falls from the third orbit to the second orbit.

(ii) The wavelength of this photon.

Ans : **Main 2000**

The energy level diagram is given by



(i) Energy of photon when falls from 3rd orbit to the 2nd orbit

$$= E_3 - E_2$$

$$= 1.51\,\text{eV} - (-3.4\,\text{eV})$$

$$= 1.9\,\text{eV}$$

(ii) So, the corresponding wavelength is given by $\frac{hc}{\lambda}$

$$\frac{hc}{\lambda} = 1.9\,\text{eV}$$

$$\lambda = \frac{hc}{1.9\,\text{eV}}$$

$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{1.9 \times 1.6 \times 10^{-19}} \quad [1\,\text{eV} - 1.6 \times 10^{-19}]$$

$$= \frac{12375}{1.9 \times 1.6 \times 10^{-19}} = 651.3\,\text{nm}$$

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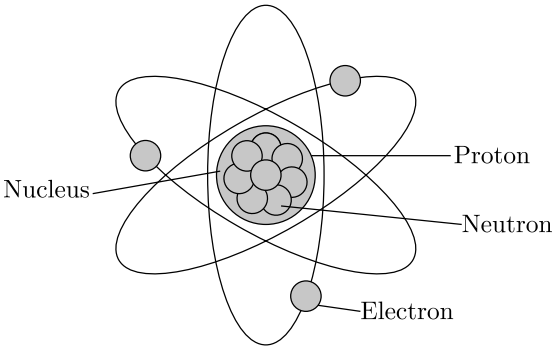
2. Neils Bohr's Improvement :
   (a) The electron can revolve only in specific orbits called stationary orbits. In these orbits, the angular momentum of an electron is an integral multiple of $\frac{h}{2\lambda}$ i.e., $mvr = \frac{nh}{2\pi}$ where n is an integer.
   (b) While revolving in such orbits, the electrons, do not emit radiations.

136. The discovery of neutrons by Chadwick, led Heisenberg propose proton-neutron hypothesis in 1932. According to this hypothesis, protons and neutrons are the main building block of all atoms. The protons are positively charged particles while neutrons are electrically neutral. The magnitude of the charge on a proton is equal to that on an electron and can be represented as $(+e)$. The number of protons in the nucleus is called atomic number Z. The total number of protons and neutrons is called mass number A. Hence, $(A - Z)$ gives the number of neutrons and is called neutron number N. A nuclear species or a nuclide is represented as ${}^{A}_{Z}X$, where X is the chemical symbol of the species.Nuclides with same atomic number Z, but different neutron number N are called isotopes. Nuclides with same mass number A are isobars and those with the same neutron number N are isotones. As most of the element are the mixture of two or more isotopes, the atomic mass of an element is the weighted average of the masses of its isotopes.



Answer the following questions from the above passage.

(i) What is atomic number in the nucleus?

(ii) What is isotope? Give one example of it.

(iii) The nuclei having same neutrons number is named as _____.

(iv) In the nucleus of ${}_{8}O^{16}$, calculate the number of protons and neutrons.

Ans :

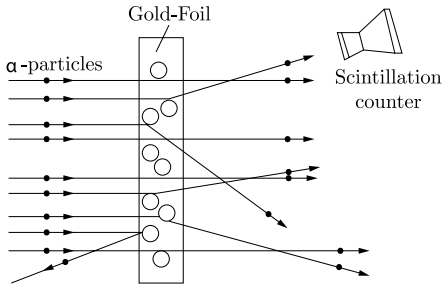
(i) The number of protons in the nucleus is known as atomic number.

(ii) Nuclides with same atomic number Z, but different neutron number N are called isotopes.
Example : ${}_{1}H^{1}$, ${}_{1}H^{2}$, ${}_{1}H^{3}$

(iii) Isotones

(iv) In ${}_{8}O^{16}$
The number of protons, $Z = 8$
The number of neutrons $= A - Z = 16 - 8 = 8$

137. In 1909, Geiger and Marsden made a series of measurements on the scattering of α-particles, which led to the discovery of atomic nucleus. Their experimental set up is shown in figure. A beam of high-energy α-particles emitted by a radioactive element polonium was made to fall on a very thin gold foil. The whole arrangement was kept in vacuum, so that there were no collisions of α-particles with air molecules. The particles, while passing through the gold foil were deflected (scattered) through a wide range of angles. The particles scattered in various directions were counted by a scintillation counter. It was found that although most of the particles scattered through angles of the order of 1° or less, but a small number, say about 1 in every 10000, scattered through 90° or even 180°. This large-angle scattering of α-particles could not be at all explained from prevalent ideas about atom at that time.



(i) Why was 'gold' foil used in α-particle scattering experiment?

(ii) For scattering of α-particles at large angles, only the nucleus of the atom is responsible, not the electron. Why?

(iii) Why was 'extremely thin' foil used?

(iv) The Rutherford's α-particle experiment shows that most of the α-particle pass through almost unscathed while some of them are scattered through large angles. What information does it give about the structure of atom?

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Ans : Main 2015

1. Energy of electron in nth orbit of hydrogen atom.

$$E_n = \frac{-13.6}{n^2}\text{ eV}$$

For $n = 1$,

$$E_1 = 13.6\text{ eV}$$

For $n = 2$,

$$E_2 = \frac{-13.6}{4} = -3.4\text{ eV}$$

Energy required to move an electron

$$= E_2 - E_1 = -3.4 - (-13.6)$$
$$= -3.4 + 13.6 = 10.2\text{ eV}$$

2. (a) Kinetic energy
(Total energy of the electron in first excited state)

$$= -(-3.41) = 3.4\text{ eV}$$

(b) Orbital radius in the state $\propto n^2$

[For first excited state, $n = 2$]

$$= 4 \times 0.53 = 2.12\text{ Å}$$

128. The ground state energy of hydrogen is -13.6 eV. What is the kinetic and potential energies of the electron in this state?

Ans : SQP 2019

Kinetic energy, $E_K = \frac{1}{2}mv^2 = \frac{1}{4\pi\varepsilon_0}\cdot\frac{e^2}{2r}$ ...(1)

Potential energy, $U = -\frac{1}{4\pi\varepsilon_0}\frac{e^2}{r}$ ...(2)

Total energy, $E = E_K + U = -\frac{1}{4\pi\varepsilon_0}\frac{e^2}{2r}$ ...(3)

Comparing equation (1), (2), (3), we have

$$E_K = -E \text{ and } U = 2E$$

Given, $E = -13.6\text{ eV}$

[For ground state, $n = 1$]

Hence, Kinetic energy,

$$E_K = 13.6\text{ eV}$$

Potential energy, $U = 2 \times (-13.6\text{ eV})$

$$= -27.2\text{ eV}$$

For second excited state,

$$n = 3$$

Hence, $E_K = -E = \frac{+13.6}{9}\text{ eV}$

$$= 1.51\text{ eV}$$

and $U = 2E = \frac{2 \times (-13.6\text{ eV})}{9}$

$$= -3.02\text{ eV}$$

129. The ground state energy of hydrogen atom is -13.6 eV. If an electron makes a transition from an energy level -0.85 eV to -3.4 eV, calculate the wavelength of the spectral line emitted. To which series of hydrogen spectrum does this wavelength belong?

Ans : SQP 2020, 2013

$$E_n = \frac{-13.6}{n^2}\text{eV} \quad ...(1)$$

For $n = 1$, $E_1 = -13.6$ eV

When electron undergoes transitions from

$$E_A = -0.85\text{ eV to } E_B = -3.4\text{ eV}$$

Then, from equation (1),we get,

$$-0.85 = \frac{-13.6}{n_A^2}$$
$$n_A = 4$$

Similarly, $-3.4 = \frac{-13.6}{n_B^2}$

$$n_B = 2$$

Hence, electron transits from $n = 4$ to $n = 2$. It corresponds to Balmer series.

We know, $\frac{1}{\lambda} = R\left(\frac{1}{n_B^2} - \frac{1}{n_A^2}\right)$

Here, $n_A = 4$, $n_B = 2$,

$$R = 1.097 \times 10^7\text{ m}^{-1}$$

Then, $\frac{1}{\lambda} = 1.097 \times 10^7\left(\frac{1}{2^2} - \frac{1}{4^2}\right)$

$$\lambda = 4862\text{Å}$$

130. The value of ground state energy of hydrogen atom is -13.6 eV.

(i) Find the energy required to move an electron from the ground state to the first excited state of the atom.

(ii) Determine (a) the kinetic energy and (b) orbital radius in the first excited state of the atom.

[Given, the value of Bohr's radius $= 0.53$Å]

Ans : SQP 2014

(i) Energy of electron in nth orbit of hydrogen atom.

$$E_n = \frac{-13.6}{n^2}\text{eV}$$

For $n = 1$

$$E_1 = -13.6\text{ eV}$$

For $n = 2$

$$E_2 = \frac{-13.6}{4} - 3.4\text{ eV}$$

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is approximately $2.3 \times 10^{17} \text{kgm}^{-3}$. This density is very large compared to ordinary matter, say water, which is 10^3kg m^{-3}. This is understandable, as we have already seen that most of the atom is empty. Ordinary matter consisting of atoms has a large amount of empty space.

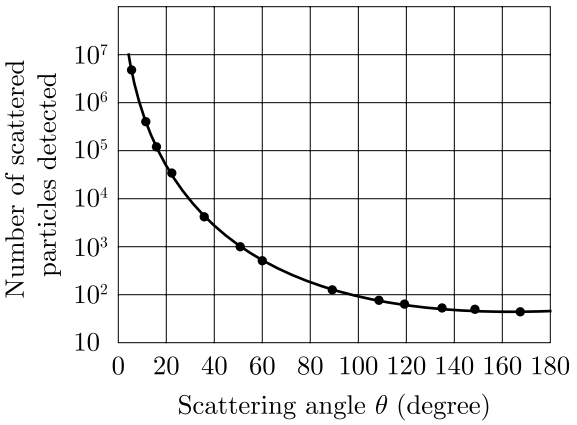
1. What is relative density of nucleus with respect to water?
2. What is the kinetic energy of α-particles bombarded towards the gold nucleus in Geiger and Marsden classic experiment?
3. What is the range of volume of hydrogen nucleus?

Ans :

1. $2.3 \times 10^{14} \text{kgm}^{-3}$
2. 8.8×10^{-13}Joule
3. 10^{-45}m

140. A typical graph of the total number of α-particles scattered at different angles, in a given interval of time, is shown in figure. The dots in this figure represent the data points and the solid curve is the theoretical prediction based on the assumption that the target atom has a small, dense, positively charged nucleus. Many of the α-particles pass through the foil. It means that they do not suffer any collisions. Only about 0.14% of the incident α-particles scatter by more than 1°; and about 1 in 8000 deflect by more than 90°. Rutherford argued that, to deflect the α-particle backwards, it must experience a large repulsive force. This force could be provided if the greater part of the mass of the atom and its positive charge were concentrated tightly at its centre. Then the incoming α-particle could get very close to the positive charge without penetrating it, and such a close encounter would result in a large deflection. This agreement supported the hypothesis of the nuclear atom. This is why Rutherford is credited with the discovery of the nucleus.

In Rutherford's nuclear model of the atom, the entire positive charge and most of the mass of the atom are concentrated in the nucleus with the electrons some distance away. The electrons would be moving in orbits about the nucleus just as the planets do around the sun. Rutherford's experiments suggested the size of the nucleus to be about 10^{-15}m to 10^{-14}m. From kinetic theory, the size of an atom was known to be 10^{-10}m, about 10,000 to 100,000 times larger than the size of the nucleus. Thus, the electrons would seem to be at a distance from the nucleus of about 10,000 to 100,000 times the size of the nucleus itself. Thus, most of an atom is empty space. With the atom being largely empty space, it is easy to see why most α-particles go right through a thin metal foil. However, when α-particle happens to come near a nucleus, the intense electric field there scatters it through a large angle. The atomic electrons, being so light, do not appreciably affect the α -particles. The scattering data shown in fig. can be analysed by employing Rutherford's nuclear model of the atom. As the gold foil is very thin, it can be assumed that α-particles will suffer not more than one scattering during their passage through it. Therefore, computation of the trajectory of an alpha-particle scattered by a single nucleus is enough. Alpha particles are nuclei of helium atom. The charge of the gold nucleus is Ze, where $Z$is the atomic number of the atom; for gold $Z = 79$. Since the nucleus of gold is about 50 times heavier than α-particle, it is reasonable to assume that it remains stationary throughout the scattering process. Under these assumptions, the trajectory of an alpha-particle can be computed employing Newton's second law of motion and the coulomb's law for electrostatic force of repulsion between the alpha-particle and the positively charged nucleus.



1. What percentage of α particle scattered at an angle more than 90°?
2. Why the nucleus of gold is about remains stationary throughout the scattering process?
3. Why electrons around the gold nucleus were unable to deflect α particles?
4. What is the ratio of charge on α particle and gold nucleus?

Ans :

1. 0.0125%
2. Because its mass is 200 times the mass of proton.
3. α particles is much heavier than electron.
4. 0.025

****

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8. If M is the atomic mass and A is the mass number, then the packing fraction is given by

(a) $\frac{M}{M-A}$ (b) $\frac{M-A}{A}$

(c) $\frac{A}{M-A}$ (d) $\frac{A-M}{A}$

Ans : SQP 2004

Given,

$$\text{Atomic mass} = M$$

and $\text{Mass number} = A$

Packing fraction is the ratio of atomic mass M minus mass number A to the mass number A i.e., $\frac{M-A}{A}$.

Thus (b) is correct option.

9. If M is atomic mass, A is mass number of a nucleus, then $\frac{M-A}{A}$ is called

(a) mass defect (b) fermi energy

(c) binding energy (d) packing fraction

Ans : SQP 2016

$$\text{Atomic mass} = M$$

and $\text{Mass number} = A$

packing fraction of a nucleus is the ratio of atomic mass M minus mass number A to the mass number A.

10. As the mass number A increase which of the following quantities related to a nucleus does not change?

(a) Mass (b) Volume

(c) Density (d) Binding energy

Ans : Main 2024

Density of nuclear matter is the ratio of mass of nucleus and its volume. It is given by,

$$\rho = \frac{3m}{4\pi R_0^3}$$

Hence density is not depends on the mass number therefore when mass number A increase than density remains constant.

Thus (c) is correct option.

11. An element has binding energy 8 eV per nucleon. If it has total binding energy of 128 eV, then the number of nucleons are

(a) 8 (b) 16

(c) 32 (d) 64

Ans : Main 2017

$$\text{Binding energy per nucleon} = 8\,\text{eV}$$

and $\text{Total binding energy} = 128\,\text{eV}$

number of nucleons,

$$N = \frac{\text{Total binding energy}}{\text{Binding energy per nucleon}}$$

$$= \frac{128}{8}$$

$$= 16$$

Thus (b) is correct option.

12. The function of heavy water in a nuclear reactor is to

(a) stop the neutrons

(b) slow down the neutrons

(c) increase the speed of neutrons

(d) none of these

Ans : Main 2013, 2011

Heavy water is rich in protons and acts as a moderator in a nuclear fission reaction in nuclear reactors. When fast moving neutrons collide head on with the protons of heavy water, they lose their energy and get slow down.

Thus (b) is correct option.

13. The energy produced in the sun is due to

(a) fission reaction

(b) fusion reaction

(c) chemical reaction

(d) motion of electrons and ions

Ans : SQP 2017

Source of the huge solar energy is the fusion of lighter nuclei. Fusion of hydrogen nuclei into helium nuclei is continuously taking place in the plasma, with a continuous liberation of energy. Therefore energy produced in the sun is due to fusion reaction.

Thus (b) is correct option.

14. Elements having different atomic number as well as different mass number, but same number of neutrons, are known as

(a) isobars (b) isotones

(c) isotopes (d) isodiaphers

Ans : SQP 2015

Isotones are atoms of different elements that have different atomic numbers and different mass numbers, but they contain the same number of neutrons. For example, Carbon-14 and Nitrogen-15 both have 8 neutrons. Since the neutron number is the same, such elements are called isotones.

Thus (b) is correct option.

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1. **Nuclear Fission :** The phenomenon of splitting of heavy nuclei (mass number > 120) into smaller nuclei of nearly equal masses is known as nuclear fission,

   e.g., $^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{141}_{56}\mathrm{Ba} + {}^{92}_{36}\mathrm{Kr} + 3{}^{1}_{0}\mathrm{n} + \mathrm{Q}$
   (where, Q = energy release in the nuclear process)
2. **Nuclear Fusion :** The phenomenon of conversion of two lighter nuclei into a single heavy nucleus is called nuclear fusion e.g.,

   $${}^{1}_{1}\mathrm{H} + {}^{1}_{1}\mathrm{H} \longrightarrow {}_{1}\mathrm{H}^{2} + \mathrm{e}^{+} + \mathrm{v} + 0.42\ \mathrm{Mev}$$

OBJECTIVE QUESTIONS

1. In a nuclear reactor, cadmium rods are used as

(a) control rods (b) fuel rods

(c) coolant (d) moderator

Ans : **Main 2020**

Cadmium rods are used as control rods in a nuclear reactor because they control the rate of fission of uranium and plutonium.

Thus (a) is correct option.

2. The elements with same atomic mass, but different atomic number, are called

(a) isobars (b) isotones

(c) isotopes (d) isochores

Ans : **Main 2009**

The elements with same atomic mass, but different atomic number are called isobars.

Thus (a) is correct option.

3. The curve of binding energy per nucleon as a function of atomic mass number has a sharp peak for helium nucleus. This implies that helium nucleus is

(a) radioactive

(b) unstable

(c) easily fissionable

(d) more stable nucleus than its neighbours

Ans : **Main 2023**

The sharp peak implies that nuclear is very stable. Binding energy per nucleon for helium nucleus is 7.0 MeV.

Thus (d) is correct option.

4. The quantities, which remain conserved in a nuclear reaction

(a) Total charge

(b) Angular momentum

(c) Linear momentum

(d) All the above

Ans : **SQP 2018**

Nuclear reactions conserve of course energy, momentum, angular momentum, charge and the total baryon number which means the total number of proton and neutrons.

Thus (d) is correct option.

5. The atomic number and mass number for a specimen are Z and A respectively. The number of neutrons in the atoms will be

(a) A (b) A

(c) $A + Z$ (d) $A - Z$

Ans : **Main 2025**

Atomic Number, Z = Number of Protons

Atomic Mass, A = Number of Protons + Number of Neutrons

Hence, $A = Z +$ Number of Neutrons

Number of Neutrons $= A - Z$

Thus (d) is correct option.

6. The number of neutrons in an atom of ${}_{90}\mathrm{Th}^{230}$ is

(a) 90 (b) 140

(c) 230 (d) 320

Ans : **Main 2012, 2010**

Number of neutron, $N =$ Mass number A − Atomic number Z

Here, Mass number, $A = 230$

Atomic number, $Z = 90$

Hence, $N = 230 - 90 = 140$

Thus (b) is correct option.

7. For uranium nucleus, how does its mass vary with volume ?

(a) $m \propto V$ (b) $m \propto V^2$

(c) $m \propto \sqrt{V}$ (d) $m \propto \frac{1}{V}$

Ans : **SQP 2008, 2010**

Mass of nucleus, m = Density × Volume

$= \rho V$

Since density of nucleus is constant, therefore its mass varies with volume i.e., $m \propto V$.

Thus (a) is correct option.

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CHAPTER 13

Nuclei

SUMMARY

1. ATOMIC MASSES

The masses of atoms, nuclei, etc., are expressed in terms of atomic mass unit represented by amu or u. For this mass of C-12 is taken as standard.

i.e., $$1u = \frac{\text{mass of one } {}^{12}C_6 \text{ atom}}{12}$$

$$= 1.660565 \times 10^{-27} \text{ Kg}$$

Mass of proton, $m_p = 1.00727$ u

Mass of neutron, $m_n = 1.00866$ u

Mass of electron, $m_e = 0.000549$ u

2. COMPOSITION OF NUCLEUS

The composition of a nucleus can be described by using the following terms and symbols.

1. **Atomic Number** (Z) **:** Atomic mass number of an element is the number of protons present inside nucleus of an atom of the element

   Atomic number = Number of protons

   = Number of electrons

2. **Mass Number** (A) **:** Mass number of an element is the total number of protons and neutrons inside the atomic nucleus of the element.

   Mass number

   = Number of protons + Number of neutrons

   = Number of electrons + Number of neutrons

   i.e., $A = Z + N$

3. SIZE OF NUCLEUS

According to experimental observations, the radius of the nucleus of an atom of mass number A is

$$R = R_0 A^{1/3}$$

Where, $R_0 = 1.2 \times 10^{-15}$ m $= 1.2$ fm

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4. MASS ENERGY EQUIVALENCE RELATION

According to Einstein, the mass and energy are equivalent i.e., mass can be converted into energy and vice-versa. The mass energy equivalence relation is

$$E = mc^2$$

Accordingly, 1 kg mass is equivalent to energy

$$= 1 \times (3 \times 10^8)^2$$

$$= 9 \times 10^{16} \text{ joules}$$

and 1 amu $(= \frac{1}{6.02 \times 10^{26}}$ kg) mass is equivalent to energy 931 MeV.

5. BINDING ENERGY

The binding energy of a nucleus is defined as the minimum energy required to separate its nucleons and place them at rest and infinite distance apart. Using Einstein's mass-energy relation,

$$\Delta E = (\Delta m) c^2$$

$$\Delta E = [Zm_p + (A - Z) m_n - M] c^2$$

$$1 \text{ amu} \cong 931.5 \text{ MeV}$$

The difference in mass of nucleus and its constituents is called mass defect.

6. BINDING ENERGY PER NUCLEON

This mass defect is in the form of binding energy of nucleus, which is responsible for binding the nucleons into a small nucleus.

Hence, Binding energy of nucleus $= (\Delta m) c^2$

and Binding energy per nucleon $= \frac{(\Delta m)}{A} c^2$

7. NUCLEAR ENERGY

Transmutation of less stable into more tightly bound nuclei provides excellent possibility of releasing nuclear energy. Two distinct ways of obtaining energy from nucleus are given as below :

15. The isotopes have

(a) same atomic number and mass number

(b) same mass number but different atomic number

(c) different atomic number and mass number

(d) same atomic number but different mass number

Ans : SQP 2011

Isotopes are atoms of the same element that contain the same number of protons, so their atomic number remains the same. However, they have different numbers of neutrons, which changes their mass number. For example, hydrogen has isotopes protium, deuterium, and tritium with different masses.

Thus (d) is correct option.

16. Which of the following is an essential requirement for initiating a fusion reaction?

(a) critical mass

(b) thermal neutrons

(c) high temperature

(d) critical temperature

Ans : SQP 2024

In a fusion reaction, two or more light nuclei get fused together to form a heavy nucleus, if they possess sufficiently high kinetic energy to overcome the force of repulsion and they can possess high kinetic energy only at very high temperature (of the order of 10^8 C).

Thus (c) is correct option.

17. If elements with principal quantum $n > 4$ were not allowed in nature, the number of possible elements would have been

(a) 4 (b) 32

(c) 60 (d) 64

Ans : Comp 2017

Given,

Principal quantum number allowed in nature, $n = 4$.

number of possible elements for principal quantum number,

$$N = \sum_{n=1}^{4} 2n^2$$

$$= 2[(1)^2 + (2)^2 + (3)^2 + (4)^2]$$

$$= 2[30] = 60$$

Thus (c) is correct option.

18. If A is the mass number of an element, then volume of the nucleus of an atom of this element is proportional to

(a) A (b) A^2

(c) A^3 (d) $A^{1/3}$

Ans : Main 2003

Mass number of element $= A$

Radius of nucleus, $R = R_0 A^{1/3}$. Therefore,

$$\text{Volume of nucleus} = \frac{4}{3}\pi R^3$$

$$= \frac{4}{3}\pi\left(R_0 A^{1/3}\right)^3$$

$$= \frac{4}{3}\pi R_0^3 A \propto A$$

Thus (a) is correct option.

Therefore, packing fraction $= \frac{M - A}{A}$

Thus (d) is correct option.

19. M_p denotes the mass of a proton and M_n that of a neutron. A given nucleus, of binding energy B, contains Z protons and N neutrons. The mass $M(N, Z)$ of the nucleus is given by ($c =$ Velocity of light)

(a) $M(N, Z) = NM_n + ZM_p - B^2$

(b) $M(N, Z) = NM_n + ZM_p + Bc^2$

(c) $M(N, Z) = NM_n + ZM_p + \frac{B}{c^2}$

(d) $M(N, Z) = NM_n + ZM_p - \frac{B}{c^2}$

Ans : SQP 2005

Mass of proton $= M_p$

Mass of neutron $= M_n$

Binding energy of the nucleus $= B$

Number of protons in the nucleus $= Z$

Number of neutrons in the nucleus $= N$

Mass of the nucleus $= M(N, Z)$

and Velocity of light $= c$

Mass defect of nucleus,

$$\Delta m = \frac{B}{c^2}$$

and this mass defect appears in the form of binding energy, which binds the nucleons together in the nucleus.

Therefore mass of the nucleus,

$$[M(N, Z)] = NM_n + ZM_p - \Delta m$$

$$= NM_n + ZM_p - \frac{B}{c^2}$$

Thus (d) is correct option.

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ASSERTION AND REASON

DIRECTION : These questions consist of two statements, each printed as Assertion and Reason. While answering these questions, you are required to choose any one of the following five responses.

20. **Assertion :** It is not possible to use ^{35}Cl as the fuel for fusion energy.

Reason : The binding energy of ^{35}Cl is too small.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **SQP 2002**

Since, ^{35}Cl is stable so binding energy is high. So it is not capable of disintegration.

Thus (c) is correct option.

21. **Assertion :** Heavy water is a better moderator than normal water.

Reason : Heavy water absorbs neutrons more efficiently than normal water.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Main 2024**

Heavy water has better ability to slow down neutrons by elastic collision between their protons and neutrons hence they are better moderators. Heavy water does not absorb neutrons.

Thus (c) is correct option.

22. **Assertion :** Isobars are the elements having same mass number but different atomic number.

Reason : Neutrons and protons are present inside nucleus.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Main 2005**

By definition, isobars are elements having same mass number but different atomic number. Presence of neutron and proton inside nucleus has nothing to do with this definition.

Thus (b) is correct option.

23. **Assertion :** Separation of isotope is possible because of the difference in electron numbers of isotope.

Reason : Isotope of an element can be separated by using a mass spectrometer.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) The Assertion is incorrect but the Reason is correct.

Ans : **Main 2010, 2006**

Isotopes of an element have the same number of electrons because they have the same atomic number. They differ only in the number of neutrons and hence in mass number. Separation of isotopes is possible due to their mass difference, and a mass spectrometer separates them on this basis.

Thus (d) is correct option.

24. **Assertion :** Neutrons penetrate mater more readily as compared to protons.

Reason : Neutrons are slightly more massive than protons.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

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Ans : **Main 2010**

Neutron is penetrate more readily as compared to protons because neutrons do not carry any change so there is no repulsion between nucleus and neutrons. So assertion is true reason is also true as mass of neutron is more than proton but reason does not explain assertion.

Thus (b) is correct option.

25. **Assertion :** Energy is released when heavy nuclei undergo fission or light nuclei undergo fusion and

Reason : For heavy nuclei, binding energy per nucleon increases with increasing Z while for light nuclei it decreases with increasing Z.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Main 2012**

Energy is released when heavy nuclei undergo fission or light nuclei undergo fusion. Therefore Assertion is correct.

The Reason is incorrect because for heavy nuclei the binding energy per nucleon decreases with increasing Z and for light nuclei, Binding energy per nucleon increases with increasing Z.

Thus (c) is correct option.

26. **Assertion :** Energy is released in nuclear fission.

Reason : Total binding energy of the fission fragments is larger than the total binding energy of the parent nucleus.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Main 2009**

Total binding energy of fragment nucleus is more than total binding energy of parent nucleus. Since, binding energy results in decrease of total energy. Hence there is great decrease in energy fragment nucleus because energy is released in nuclear fission.

$$\underset{\text{(Parent)}}{A} \longrightarrow \underset{\text{(Fragment)}}{B} + \underset{\text{(Energy)}}{E}$$

Energy of B is decrease but the binding energy of B is increased due to release of energy from it. So, reason supports the assertion.

Thus (a) is correct option.

27. **Assertion :** The binding energy per nucleon, for nuclei with a atomic mass number $A > 100$, decreases with A.

Reason : The nuclear forces are weak for heavier nuclei.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **SQP 2007**

Binding energy per nucleon decreases with A for nuclei with atomic mass number $A > 100$ due to weak nuclear forces. It can be explain as :

At short distances, the nuclear force is stronger than the Coulomb force; it can overcome the Coulomb repulsion of protons inside the nucleus. At typical nucleon separation (1.3 fm) if is a very strong attractive force (104 newtons). Beyond about 1.3 fm separation, the force exponentially dies off to zero. However, the Coulomb force between protons has a much larger range and become the only significant force between protons when their separation exceeds about (2.5 fm, $A > 100$).

Thus (a) is correct option.

28. **Assertion :** Between any two given energy levels, the number of absorption transitions is always less than the number of emission transitions.

Reason : Absorption transitions start from the lowest energy level only and may end at any higher energy level. But emission transitions may start from any higher energy level and end at any energy level below it.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

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Ans : SQP 2014

(a) Cadmium rods are used to control the rate of nuclear fission as it absorbs the extra neutron.

(b) Graphite rods are used to slow down the fast moving neutrons.

53. State any two differences between nuclear fusion and nuclear fission.

Ans : SQP 2023

A fission reaction is splitting up of a large atom or a molecule into two or more smaller ones, Fusion is the process of combination of two or more lighter atoms or molecules into larger ones.

54. Write one balanced equation each to show

(i) nuclear fission

(ii) nuclear fusion

Ans : Main 2018

(i) $4\,{}_1^1\mathrm{H} + 2e^- \longrightarrow {}_2^4\mathrm{He} + 2v + 6\gamma + 26.7\ \mathrm{MeV}$

(ii) For nuclear fusion

${}_1\mathrm{H}^2 + {}_1\mathrm{H}^2 \longrightarrow {}_1\mathrm{H}^3 + {}_1\mathrm{H}^1 +$ Energy

55. He_2^3 and He_1^3 nuclei have the same mass number. Do they have the same binding energy?

Ans : Main 2010

Nuclei He_2^3 and He_1^3 have the same mass number. He_2^3 has two protons and one neutron. He_1^3 has one proton and two neutrons. The repulsive force between protons is missing in ${}_1\mathrm{He}^3$, so the binding energy of ${}_1\mathrm{He}^3$ is greater than that of ${}_2\mathrm{He}^3$.

56. A chain reaction dies out sometimes. Why?

Ans : SQP 2024

A chain reaction may die out due to any of the following causes:

1. Excessive neutron leakage if the size of the fissionable material is smaller than the critical size.
2. Fast neutrons may escape the fissionable material without causing further fissions.
3. Some neutrons may suffer non-fission capture by ${}_{92}^{238}\mathrm{U}$ nuclei.

57. What is Einstein's mass-energy equivalence? What is its importance?

Ans : Main 2010

In his special theory of relativity, Einstein showed that,

$$E = mc^2$$

This equation expresses equivalence between mass and energy. Thus the energy content of an object is its mass times the square of the speed of light. This principle is central to our understanding of nuclear energy and harnessing it as a source of power. Using this principle, the Q-value of nuclear process can be expressed in terms of initial and final masses.

58. In a typical nuclear reaction. e.g.,

${}_1^2\mathrm{H} + {}_1^2\mathrm{H} \longrightarrow {}_2^3\mathrm{He} + n + 3.27$

Although number of nucleons is conserved yet energy is released. How? Explain.

Ans : SQP 2012

In a nuclear reaction, the sum of the masses of the larger nucleus $({}_1^2\mathrm{H})$ and the bombarding particle $({}_1^2\mathrm{H})$ may be greater or less than the $({}_1^3\mathrm{He})$ and the outgoing particle $({}_0^1 n)$. So, from the law of conservation of mass-energy, some energy (3.27 MeV) is evolved or involved in a nuclear reaction. This energy is called Q-value of the nuclear reaction,

59. Name any two essential parts of a nuclear reactor. State the function of any one of them.

Ans : Main 2023

Essential parts of a nuclear reactor are as follows :

1. Fuel
2. Moderator
3. Control rods
4 Coolant
5. Pressure tubes
6. Steam generator

Control roads : The control rods are made up of cadmium or boron. The function of this control rod is to absorb the neutron efficiently. It can also be used to shut down the reactor.

60. What are isotopes and isobars? Give suitable examples.

Ans : Main 2012

The atoms of an element which have the same atomic number but different mass number are called isotopes. Lithium has two isotopes : ${}_3^6\mathrm{Li}$ and ${}_3^7\mathrm{Li}$. Gold has 32 isotopes, ranging from $A = 173$ to 204.

Isobars

The atoms having the same mass number but different atomic number are called isobars. Such atoms contain different number of protons and electrons.

Examples of isobars are:

1. ${}_{17}^{37}\mathrm{Cl}$ and ${}_{16}^{37}\mathrm{S}$, as both have same $A = 37$.
2. ${}_{20}^{40}\mathrm{Ca}$ and ${}_{18}^{40}\mathrm{Ar}$, as both have same $A = 4$.

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41. Complete the following nuclear reaction,

$$^{1}_{0}n + ^{12}_{6}\text{C} \longrightarrow ^{11}_{5}\text{B} + ...$$

Ans : **Main 2010**

When a neutron reacts with carbon, it gives hydrogen with boron.

$$^{1}_{0}n + ^{12}_{6}\text{C} \longrightarrow ^{11}_{5}\text{B} + ^{2}_{1}\text{H}$$

42. What is the role of control rods in a nuclear reactor?

Ans : **Comp 2004**

A control rod is used in nuclear reactor to control the rate of fission of uranium and plutonium. They are made of chemical elements capable of absorbing many neutrons, such as boron, cadmium, etc.

43. What is the function of heavy water in a nuclear reactor?

Ans : **Main 2024**

Heavy water is used as a moderator in a nuclear reactor. It is used to slow the fast moving neutrons being directed at the fissionable material by means of the molecules of the moderator.

44. Write any two characteristic properties of nuclear force.

Ans : **SQP 2008**

Two characteristic of nuclear force are given as below:

1. These are short range forces.
2. These are strong force of attractive nature.

45. What is meant by pair annihilation? Write a balanced equation for the same.

Ans : **Comp 2018**

The phenomenon in which energy is converted into mass is called pair-production and is expressed as

$$\underset{(\gamma-\text{photon})}{h\nu} = \underset{\text{(electron)}}{{}_{-1}\beta^{0}} + \underset{\text{(positron)}}{{}_{+1}\beta^{0}}$$

46. Write the relationship between the size of a nucleus and its mass number (A).

Ans : **SQP 2012, 2011**

The relationship between the size of a nucleus and it mass number is given by

$$R = R_o A^{1/3}$$

Where, R = radius of nucleus

A = mass number

47. What is the minimum energy which a gamma ray photon must possess in order to produce electron-positron pair?

Ans : **Main 2017**

γ-rays are neutral photons of electromagnetic nature. After an α- or β- decay, the daughter nuclei is usually left in the excited state. It attains the ground state by single or successive transitions by emitting one or more photons. These energies of the order of MeV.

48. Identify the nuclide X and Y in the nuclear reactions.

$$_{5}\text{B}^{11} + _{1}\text{H}^{1} \longrightarrow _{4}\text{Be}^{8} + X \text{ and } _{6}\text{C}^{14} \longrightarrow Y + _{-1}e^{0}$$

Ans : **Main 2001**

In the nuclear reaction,

$$_{5}\text{B}^{11} + _{1}\text{H}^{1} \longrightarrow _{4}\text{Be}^{8} + X(_{2}\text{He}^{4})$$

Here, the product is doubly ionised. So, X is an α -particle i.e., doubly ionised helium atom $(_{2}\text{He}^{4})$.

Now, in reaction $_{6}\text{C}^{14} \longrightarrow Y(_{7}\text{C}^{14}) + _{-1}e^{0}$

As, only one electron is released here, thus Y is an isotope of carbon $_{7}\text{C}^{14}$.

TWO MARKS QUESTIONS

49. What characteristic property of nuclear force explains the constancy of binding energy per nucleon (BE/A) in the range of mass number. 'A'....lying $30 < A < 170$?

Ans : **Main 2012, 2015**

Saturation or short range nature of nuclear forces.

50. What is the essential difference between the working of a fission bomb and a nuclear reactor?

Ans : **Comp 2018**

In a nuclear reactor controlled chain reaction takes place whereas, In a fission bomb uncontrolled chain reaction takes place.

51. Write a balance equation showing nuclear fission of uranium $(^{235}_{92}\text{U})$ nucleus.

Ans : **Main 2010**

The balanced equation showing nuclear fusion of $^{235}_{92}\text{U}$ is

$$_{92}\text{U}^{235} + _{0}n^{1} \longrightarrow _{56}\text{Ba}^{141} + _{36}\text{Kr}^{92} + 3\,_{0}n^{1} + \text{Energy}$$

52. In a nuclear reactor, what is the function of

(a) cadmium rods

(b) graphite rods.

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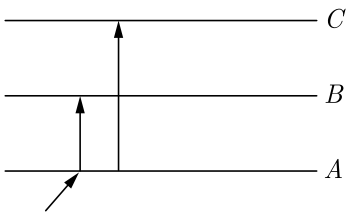
(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

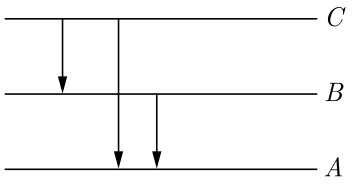
(d) Both the Assertion and Reason are incorrect.

Ans : SQP 2010

Absorption transition



Two possibilities in absorption transition.



Three possibilities in emission transition. Therefore, absorption transition $<$ emission.

Thus (a) is correct option.

ONE MARK QUESTIONS

29. What is pair production?

Ans : Main 2020

The phenomenon in which energy is converted into mass is called pair-production.

30. Name any one material used as a moderator in a nuclear reactor.

Ans : SQP 2018, 2011

Heavy water (D_2O).

31. What is the source of energy of stars?

Ans : Main 2025

Nuclear fusion reaction takes place at the sun to release tremendous amount of energy.

32. State the function of a moderator in a nuclear reactor.

Ans : SQP 2023

It is a medium that slows down the fast moving secondary neutrons. D_2O, graphite, beryllium, etc.

33. Name a material which is used in making control rods in a nuclear reactor.

Ans : Main 2018

Cadmium or boron is used in making control rods in a nuclear reactor.

34. Where in our universe is the thermonuclear energy being released naturally?

Ans : Main 2016, 2009

Nuclear reaction takes place at the stars and the sun. Hydrogen get converted to helium.

35. Write any one balanced equation representing nuclear fission.

Ans : Main 2015

Nuclear fission

$$ {}^{1}_{0}n + {}^{235}_{92}\mathrm{U} \longrightarrow {}^{144}_{56}\mathrm{Ba} + {}^{89}_{36}\mathrm{Kr} + 3\,{}^{1}_{0}n $$

36. Write one balanced reaction representing nuclear fusion.

Ans : Main 2014

$$ 4\,{}^{1}_{1}\mathrm{H} + 2e^{-} \longrightarrow {}^{4}_{2}\mathrm{He} + 2v + 6\gamma + 26.7\ \mathrm{MeV} $$

37. What is meant by mass defect?

Ans : Main 2019

The sum of the masses of neutrons and protons forming a nucleus is more than the actual mass of the nucleus. This difference of masses is known as mass defect.

38. Name the type of nuclear reaction that takes place in the core of the Sun.

Ans : Main 2023

Nuclear fusion reaction takes place in the Sun. The Sun's tremendous pressure and high temperature fuse hydrogen nuclei to form helium through various steps.

39. In a nuclear reactor, what is the function of a moderator?

Ans : Main 2016

In a nuclear reactor, the function of moderator is to slow down the fast moving secondary neutrons produced during the fission.

40. Consider the following nuclear reaction,

$$ {}^{2}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \longrightarrow {}^{3}_{2}\mathrm{He} + {}^{1}_{0}n $$

What is the name of this reaction?

Ans : Main 2011

The given reaction shows that two atoms are combining to form third atom and a neutron released from it. Thus, it is a nuclear fusion reaction.

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61. What are isotones and isomers? Give suitable examples.

Ans : **SQP 2015**

Isotones : The nuclides having the same number of neutrons are called isotones. For example, $^{37}_{17}\text{Cl}$ and $^{39}_{19}\text{K}$ are isotones, as both contain the same number of neutrons i.e., for both $N = A - Z = 20$.

Isomers : These are the nuclei with same atomic number and same mass number but existing in different energy states. For example, a nucleus in its ground state and the identical nucleus in metastable excited state are isomers.

62. State the necessary conditions for nuclear fusion to occur.

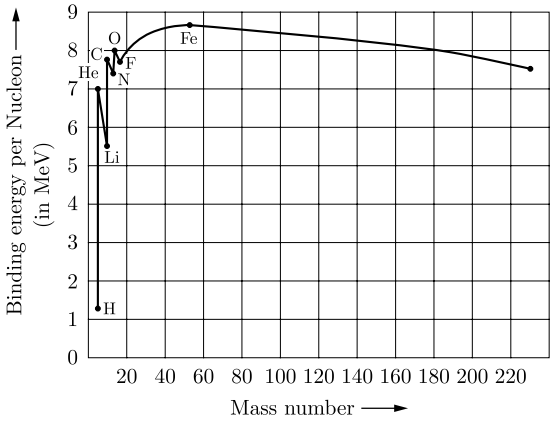
Ans : **Main 2025**

The fusion reactions take place under the conditions of extreme temperature and density due to the following reasons :

1. The high temperature is necessary for the light nuclei to have sufficient kinetic energy so that they can overcome their mutual coulombic repulsions and come closer than the range of nuclear force. That is why a fusion reaction is also called a thermonuclear reaction.
2. High density or pressure increases the frequency of collision of light nuclei and hence increases the rate of fusion.

63. Sketch a graph showing the variation of binding energy per nucleon of a nucleus with its mass number.

Ans : **Main 2017**



64. Why nuclear fusion reaction is also called thermo-nuclear reactions?

Ans : **Main 2017**

To carry nuclear fusion in a bulk material, the temperature of the material has to be raised to 10^6 K. A high temperature is necessary for the light nuclei to have sufficient kinetic energy so that they can overcome their mutual coulombic repulsion and come closer than the range of nuclear force. Colliding nuclei should have enough energy due to their thermal motion and can penetrate the coulomb barrier. That's why nuclear fusion reaction is also known as thermo-nuclear reaction as it involves lot of heat.

65. Define multiplication factor of a fissionable mass. Give its physical significance.

Ans : **Main 2008**

The multiplication factor of a fissionable mass is defined as the ratio of the number of neutrons present at the beginning of a particular generation to the number of neutrons present at the beginning of the previous generation.

Thus,

$$k = \frac{\text{Number of neutrons present at the beginning of one generation}}{\text{Number of neutrons present at the beginning of previous generation}}$$

The multiplication factor k gives a measure of the growth rate of the neutrons in a fissionable mass.

If $k > 1$, the chain reaction grows.

If $k = 1$, the chain reaction remains steady.

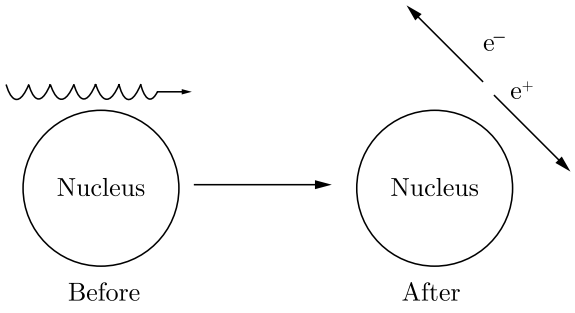
If $k < 1$, the chain reaction gradually dies out.

66. With the help of a suitable example and an equation, explain the term pair production.

Ans : **Main 2015**

When a photon passes near a massive particle like an atomic nucleus, the photon disappears by creating an electron-positron pair. This process is called pair production. The energy of the photon should be equal to sum of energy of electron and energy of positron.

So, a photon must have an energy of at least $2m_0c^2$ to create an electron positron pair, where, m_0 is the rest mass of the electron.



To conserve momentum, the nucleus recoils with very small velocity. Pair production is also known as the materialisation of radiant energy.

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FOUR MARKS QUESTIONS

88. Prove that the density of a nucleus independent of its mass number.

Ans : **Main 2014, 2009**

The radius R of nucleus is related to its mass number (A) as :

$$R = R_0 A^{1/3}$$

where, $R_0 = 1.1 \times 10^{-15}$ m

If m is average mass of nucleon, then mass of nucleus $= mA$,

where , A is mass number.

$$\text{Volume of nucleus} = \frac{4}{3}\pi R^3$$

$$= \frac{4}{3}\pi (R_0 A^{1/3})^3 = \frac{4}{3}\pi R_0^3 A$$

Density of nucleus,

$$\rho_N = \frac{\text{mass}}{\text{volume}}$$

$$= \frac{mA}{\frac{4}{3}\pi R_0^3 A} = \frac{m}{\frac{4}{3}\pi R_0^3}$$

Clearly, nuclear density, ρ_N is independent of mass number A.

89. How is the size of a nucleus found experimentally? Write the relation between the radius and mass number of a nucleus.

Ans : **Comp 2025**

Nucleus was first discovered in 1911 by Lord Rutherford and his associates by experiments on scattering of α-particles by atoms. He found that the scattering result could be explained, if atoms consists of a small central massive and positive core surrounded by orbiting electron. The experiment results indicated that the size of the nucleus is of the order of 10-14 meters and is thus, 10,000 times smaller than the size of the atom.

The size of nucleus is obtained by the point of closest approach of an alpha-particle. By shooting alpha particles of kinetic energy 5.5 MeV. The point of closest approach was estimated to be about 4×10^{-14} m. Since, the repulsive force acting here is coulomb repulsion, there is no contact. This means that the size of the nucleus is smaller than 4×10^{-14} m.

Relation between radius and mass number is

$$R = R_0 A''_3$$

where, $R_0 = 1.2 \times 10^{-15}$m

and A is the mass number

90. Distinguish between nuclear fission and fusion giving an example of each.

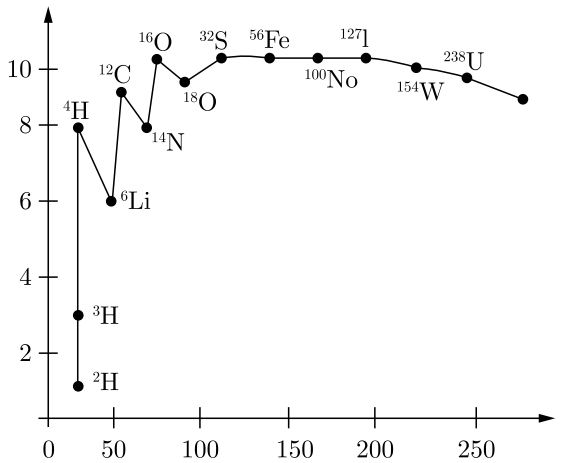
Ans : **SQP 2023**

The difference between nuclear fission and fusion are as follows :

	Nuclear Fission	**Nuclear Fusion**
1.	When the nucleus of an atom splits into lighter nuclei through a nucleus reaction the process is termed nuclear fission.	Nuclear fusion is a reaction through which two or more light nuclei collide with each other to form a heavier nucleus.
2.	When each atom splits a tremendous amount of energy is released.	The energy released during nuclear fusion is several times greater than the energy released during nuclear fission.
3.	Fission reactions do not occur in nature naturally.	Fusion reactions occur in stars and the sun.
4.	Comparatively, less energy is needed to split an atom in a fission reaction.	High energy is needed to fuse two or more atoms together in a fusion reaction.
5.	Atomic bomb works on this principle.	Hydrogen bomb works on this principle.

91. Explain the release of energy in nucleus and fission and fusion on the basis of binding energy per nucleon curve.

Ans : **Main 2017**



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THREE MARKS QUESTIONS

72. Write three characteristic properties of nuclear force.

Ans : **Main 2012, 2015**

Characteristic properties of nuclear force are as follows :

(a) Nuclear force act between a pair of neutrons, a pair of protons and also between a neutron-proton pair, with the same strength. This shows that nuclear forces are independent of charge.

(b) The nuclear forces are dependent on spin or angular momentum of nuclei.

(c) Nuclear forces are non-central firces. This shows that the distribution of nucleons in a nucleus is not spherically symmetric.

73. Answer the following :

1. Why is the binding energy per nucleon found to be constant for nuclei in the range of mass number A lying between 30 and 170?
2. When a heavy nucleus with mass number $A = 240$ breaks into two nuclei, $A = 120$, energy is released in the process.

Ans : **SQP 2025**

1. The binding energy per nucleon for nucleus of range, $30 < A < 170$ is close to its maximum value. So, the nucleus belongs to this region is highly stable and does not show radioactivity.
2. Binding energy per nucleon is smaller for heavier nuclei than the middle ones, i.e., heavier nuclei are less stable. When a heavier nucleus such as nucleus of mass number 240 splits into lighter nuclei (mass number 120), the BE/nucleon changes from 7.6 MeV to 8.4 MeV. Greater BE of the product nuclei result in the liberation of energy.

74. What are uncontrolled and controlled chain reactions?

Ans : **Main 2006**

Uncontrolled Chain Reaction : If a chain reaction is started in a fissionable material having mass greater than certain critical mass, then the reaction will accelerate at such a rapid rate that the whole material will explode within a microsecond, liberating a huge amount of energy. Such a chain reaction is called uncontrolled chain reaction. It forms the underlying principle of the atomic bombs.

Controlled Chain Reaction : The chain reaction can be controlled and maintained steady by absorbing a suitable number of neutrons at each stage of the reaction, so that on an average one neutron remains available for exciting further fission. Such a reaction is called controlled chain principle of a controlled chain reaction.

75. Show that the density of nucleus over a wide range of nuclei is constant independent of mass number A.

Ans : **SQP 2015**

The radius (size) R of nuclear is related to its mass number (A) as

$$R = R_0 A^{1/3}$$

where, $R_0 = 1.1 \times 10^{-15}$ m

If m is the average mass of a nucleon, then mass of nucleus $= mA$, Where A is mass number.

$$\text{Volume of nucleus} = \frac{4}{3}\pi R^3 = \frac{4}{3}\pi (R_0 A^{1/3})^3$$

$$= \frac{4}{3}\pi R_0^3 A$$

Hence, density of nucleus,

$$\rho_N = \frac{\text{Mass}}{\text{Volume}}$$

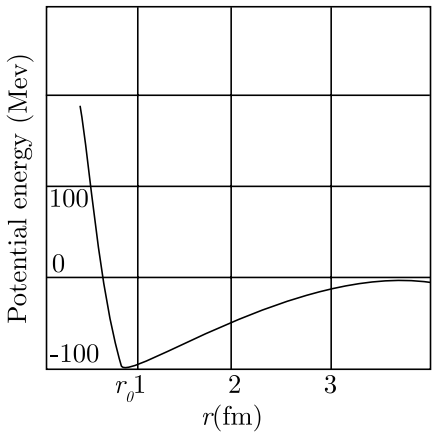
$$= \frac{mA}{\frac{4}{3}\pi R_0^3 A}$$

$$= \frac{m}{\frac{4}{3}\pi R_0^3} = \frac{3m}{4\pi R_0^3}$$

Clearly, nuclear density ρ_N is independent of mass number A.

76. Draw a plot of potential energy of a pair of nucleons as a function of their separation. Write two important conclusions that can be drawn from the graph.

Ans : **Main 2017, 2011**



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67. What is mass defect of a nucleus? Express it mathematically. What light does it throw on the binding energy of nucleus?

Ans : **Comp 2012**

The difference between the rest mass of a nucleus and the sum of the rest masses of its constituent nucleons is called its mass defect.

Consider the nucleus ${}^{A}_{Z}X$. It has Z protons and $(A-Z)$ neutrons. Therefore, its mass defect will be,

$$\Delta m = Zm_p + (A-Z)\,m_n - m$$

where, m_p, m_n and m are the rest masses of a proton, neutron and the nucleus ${}^{A}_{Z}X$ respectively.

When a nucleus is formed from its nucleons, some of their mass is converted into energy which binds the nucleons together inside the nucleus. This energy, called binding energy, is equivalent of mass defect.

68. What are the utilities of moderator, coolant and controlling rods with reference to unclear reactor?

Ans : **SQP 2014, 2009**

1. **Moderator :** It is a medium to slow down the fast moving secondary neutrons produce during the fission. Heavy water, graphite, deuterium, paraffins, etc., acts as moderator.
2. **Control Rods :** It is used in nuclear reactors to control the rate of fission of uranium and plutonium. These are made of chemical element capable of absorbing many neutrons without fissioning themselves such as silver, indium, boron and cadmium.
3. **Coolant :** It is a liquid used to remove heat from nuclear reactor core and transfer it to electrical generator and environment. Ordinary water under high pressure is used as coolant.

69. State the important properties of neutrons.

Ans : **SQP 2010**

Some important properties of neutrons are as follows :

1. Neutron is an elementary particle present in the nuclei of all elements except hydrogen.
2. Neutron has no charge and its mass is slightly more than that of a proton,
$$m_n = 1.00866\ \text{amu}$$
$$= 1.6749 \times 10^{-27}\ \text{kg}$$
3. A free neutron is unstable. It spontaneously decays into a proton, electron and an anti-neutrino with a half life of about 1000 s.
$${}^{1}_{0}n \longrightarrow {}^{1}_{1}\text{H} + {}^{0}_{-1}e + \overline{\nu} + Q$$
4. Neutrons being neutral, have low ionising power.
5. Being neutral, neutrons are not repelled or attracted by the nucleus and the electrons of an atom. They can easily penetrate heavy nuclei and induce nuclear reactions.

70. How is the size of a nucleus estimated? Write the relation between the radius of a nucleus and its mass number.

Ans : **Main 2005, 2001**

A nucleus can be considered to be spherical in shape. By performing scattering experiments using high energy electrons, we can determine its radius accurately.

Experimental observations show that the volume of a nucleus is directly proportional to its mass number. If R is the radius of a nucleus having mass number A, then

$$\frac{4}{3}\pi R^2 \propto A$$
$$R \propto A^{1/3}$$
$$R = R_0 A^{1/3}$$

Thus, the radius R of a nucleus is proportional to the cube root of its mass number. The value of constant R_0 depends on the nature of probe particles.

For electrons, $R_0 = 1.2 \times 10^{-15}\,\text{m} = 1.2\,\text{fm}$

71. What are nuclear forces? Give their important properties.

Ans : **Main 2010**

The strong attractive forces acting between the protons and neutrons of a nucleus which keep them bound together inside the tiny nucleus are called nuclear forces.

The important properties of nuclear forces are as follows:

1. Nuclear forces are the strongest attractive forces known in nature,
$$F_G : F_E : F_N = 1 : 10^{36} : 10^{38}$$
2. They are short range forces effective upto 2-3 fermi from a nucleon.
3. They have charge independent nature.
4. They show saturation effect i.e., a nucleon can interact only with a neighbouring nucleon.
5. They are non-central forces i.e., they do not act along the line joining the centres of the two nucleons.

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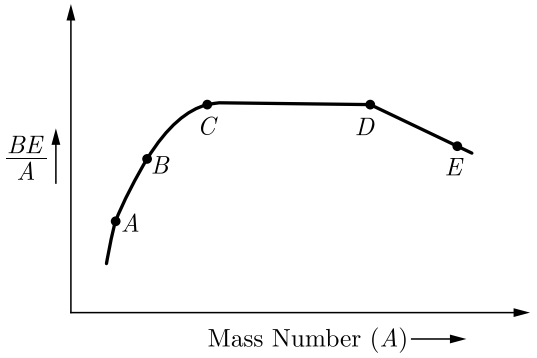
2. Identify the nature of the radioactive radiations emitted in each step of the decay process given below,

$${}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y \rightarrow {}^{A-4}_{Z-1}W$$



Ans : **Main 2004**

1. Nuclear fission of E to D and C; as there is an increase in binding energy per nucleon.

   Nucleon fusion of A and B into C; as there is an increase in binding energy per nucleon.

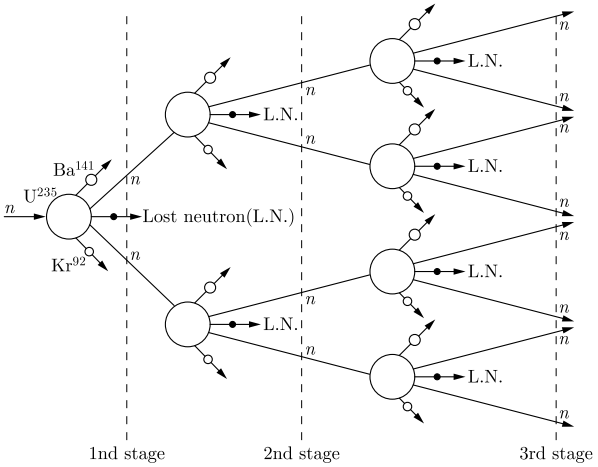
2. First step α particle, as the atomic number decreases by 2 and mass number decreases by 4.

   Second step β particle, as the atomic number increases by 1, while mass number remains unchanged.

81. What is nuclear fission? Explain how a chain reaction can occur in a fissionable material?

Ans : **Main 2012**

Nuclear fission is a peculiar type of reaction which, besides the other fission products, produces the same kind of particles that initiate it, viz., neutrons.



A Chain Reaction in ${}^{235}_{92}\mathrm{U}$

When a single ${}^{235}_{92}\mathrm{U}$ nucleus captures a neutron, its fission produces 2.5 neutrons. These freshly produced neutrons can further cause the fission of more uranium nuclei, producing still more neutrons, which can further cause the fission of a larger number of nuclei and so on. The number of fissions taking place at each successive stage goes on increasing at a rapid rate (rather in a geometric progression). Thus a chain reaction is set up, as illustrated in figure. Enrico Fermi first suggested possibility of such a reaction in 1939.

82. What so you mean by Nuclear Fission?

Ans : **Main 2024**

The phenomenon of splitting of heavy nuclei (mass number > 120) into smaller nuclei of nearly equal masses is known as nuclear fission.

In nuclear fission, the sum of the masses of the product is less than the sum of masses of the reactants. This difference of mass gets converted into energy $E = mc^2$ and hence sample amount of energy is released in a nuclear fission.

e.g., ${}^{235}_{92}\mathrm{U} + {}^{1}_{0}n \rightarrow {}^{141}_{56}\mathrm{Ba} + {}^{92}_{36}\mathrm{Kr} + 3{}^{1}_{0}n + Q$

$$\begin{aligned}
\text{Masses of reactant} &= 235.0439\,\text{amu} + 1.0087\,\text{amu} \\
&= 236.0526\,\text{amu} \\
\text{Masses of product} &= 140.9139 + 91.8973 + 3.0261 \\
&= 235.8373\,\text{amu} \\
\text{Mass defect} &= 236.0526 - 235.8373 \\
&= 0.2153\,\text{amu} \\
\text{Hence,} \quad 1\,\text{amu} &= 931\,\text{MeV} \\
\text{Energy released} &= 0.2153 \times 931 \\
&= 200\,\text{MeV nearly}
\end{aligned}$$

Thus, energy is liberated in nuclear fission, if ${}^{235}_{92}\mathrm{U}$

83. Show that nuclear density in a given nucleus is independent of mass number A.

Ans : **SQP 2012**

Density of nuclear matter is the ratio of mass of the nucleus and its volume.

Density of the nuclear matter

$$= \frac{\text{Mass of nucleus}}{\text{Volume of nucleus}} \qquad ...(1)$$

If m is average mass of a nucleus and R is the nuclear radius, then mass of nucleus $= mA$, where A is the mass number of the element.

$$\text{Volume of the nucleus} = \frac{4}{5}\pi R^3$$

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$$= \frac{4}{5}(\pi R_0 A^{1/3})^3$$

$$= \frac{4}{3}\pi R_0^3 A$$

Put the value in equation (1), we get

Thus, density of nucleus $= \dfrac{mA}{\frac{4}{3}\pi R_0^3 A} = \dfrac{3m}{4\pi R_0^3}$

As, m and R_0 are constants, therefore density of the nuclear matter is the same for all elements. Now, using $m = 1.66 \times 10^{-27}$ kg.

$$= \frac{3 \times 1.66 \times 10^{-27}}{4\pi R_0^3}$$

Using, $R_0 = 1.1 \times 10^{-15}\ m$ and

$$\text{Density} = 2.97 \times 10^{17}\ \text{kg}\, m^{-3}$$

Which shows that the density is independent of mass number A.

84. Distinguish between nuclear fission and fusion. Show how in both these processes energy is released. Calculate the energy release in MeV in the deuterium fusion reaction.

$$^2_1\text{H} + {}^3_1\text{H} \longrightarrow {}^4_2\text{He} + n$$

Using the data

$$m(^2_1\text{H}) = 2.014102\ \text{u}$$

$$m(^3_1\text{H}) = 3.016049\ \text{u}$$

$$m(^4_2\text{He}) = 4.002603\ \text{u}$$

$$m_n = 1.008665\ \text{u}$$

$$1\text{u} = 931.5\frac{\text{MeV}}{c^2}$$

Ans : **Main 2015**

Nuclear fission is the phenomenon of splitting of a heavy nucleus (usually $A > 230$) into two or more lighter nuclei.

$\text{U}^{235}_{92} + n^1_0 \longrightarrow \text{Ba}^{141}_{56} + \text{Kr}^{92}_{36} + 3n^1_0 + Q$

In this case, the energy released per fission of U^{235}_{92} is 200.4 MeV.

Nuclear fission is the phenomenon of fusion of two or more lighter nuclei to form a single heavy nucleus. The mass of the product nucleus is slightly less than the sum of the masses of the lighter nuclei fusing together. This difference in the masses results in the release of tremendous amount of energy. e.g.,

$^1_1\text{H} + {}^1_1\text{H} \longrightarrow {}^2_1\text{He} + e^+ + v + 0.42\ \text{MeV}$

$^2_1\text{H} + {}^2_1\text{H} \longrightarrow {}^3_1\text{He} + n + 3.27\ \text{MeV}$

$^2_1\text{H} + {}^2_1\text{H} \longrightarrow {}_1\text{He}^3 + {}^1_1\text{H} + 40.3\ \text{MeV}$

$^2_1\text{H} + {}^3_1\text{H} \longrightarrow {}^4_2\text{He} + n\text{MeV}$

$$\Delta m = (2.014102 + 3.016049) - (4.002603 + 1.008665)$$

$$= 0.018883\ \text{u}$$

$$\text{Energy released, } Q = 0.018883 \times 931.5\frac{\text{MeV}}{c^2}$$

$$= 17.589\ \text{MeV}$$

85. Explain giving necessary reaction, how energy is released during:

(i) fission

(ii) fusion

Ans : **Main 2011**

(i) **Nuclear Fission :** The phenomenon of splitting of heavy nuclei (mass number > 120) into smaller nuclei of nearly equal masses is known as nuclear fission.

In nuclear fission, the sum of the masses of the product is less than the sum of masses of the reactants. This difference of mass gets converted into energy $E = mc^2$ and hence sample amount of energy is released in a nuclear fission.

e.g., $^{235}_{92}\text{U} + {}^1_0 n \rightarrow {}^{141}_{56}\text{Ba} + {}^{92}_{36}\text{Kr} + 3{}^1_0 n + Q$

$$\text{Masses of reactant} = 235.0439\ \text{amu} + 1.0087\ \text{amu}$$

$$= 236.0526\ \text{amu}$$

$$\text{Masses of product} = 140.9139 + 91.8973 + 3.0261$$

$$= 235.8373\ \text{amu}$$

$$\text{Mass defect} = 236.0526 - 235.8373$$

$$= 0.2153\ \text{amu}$$

$$\text{Hence, } 1\ \text{amu} = 931\ \text{MeV}$$

$$\text{Energy released} = 0.2153 \times 931$$

$$= 200\ \text{MeV nearly}$$

Thus, energy is liberated in nuclear fission.

(ii) **Nuclear Fusion :** The phenomenon of conversion of two lighter nuclei into a single heavy nucleus is called nuclear fusion. Since, the mass of the heavier product nucleus is less than the sum of masses of reactant nuclei and therefore certain mass defect occurs which converts into energy as per Einstein's mass-energy relation. Thus, energy is released during nuclear fusion.

e.g., $_1\text{H}^1 + {}_1\text{H}^3 \longrightarrow {}_1\text{H}^2 + e^+ + v + 0.42\ \text{MeV}$

Also, $_1\text{H}^2 + {}_1\text{H}^2 \longrightarrow {}_1\text{H}^3 + {}_1\text{H}^1 + 4.03\ \text{MeV}$

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86. Give reason for :

(a) Lighter elements are better moderators for a nuclear reactor than heavier elements.

(b) In a natural uranium reactor, heavy water is preferred moderator as compared to ordinary water.

(c) Cadmium rods are provided in a reactor.

(d) Very high temperature as those obtained in the interior of the sun are required for fusion reaction.

Ans : **SQP 2017**

(a) A moderator slows down fast neutrons released in a nuclear reactor. The basic principle of mechanics is that the energy transfer in a collision is the maximum when the colliding particles have equal masses. As lighter elements have mass close to that of neutrons, lighter elements are better moderators than heavier elements.

(b) Ordinary water has hydrogen nuclei ($_1^1H$) which have greater absorption capture for neutrons; so ordinary water will absorb neutrons rather than slowing them; on the other hand the heavy hydrogen nuclei ($_2^1H$) have negligible absorption capture for neutrons, so they share energy with neutrons and neutrons are slowed down.

(c) Cadmium has high absorption capture for neutrons; so cadmium rods are used to absorb extra neutrons; so nuclear fission in a nuclear reactor is controlled; therefore cadmium rods are called control rods.

(d) In nuclear fusion, two positively charge nuclei fuse together, when two positively charged nuclei come near each other to fuse together, strong electrostatic repulsive force acts between them. To overcome this repulsive force, extremely high temperature of the order of 10^8 K are required. This may be calculated as follows :

For fusion of H-nuclei,

$$\frac{1}{4\pi\varepsilon_0}\frac{e^2}{r} = \text{KT}$$

$$9 \times 10^9 \times \frac{(1.6 \times 10^{-19})^2}{10^{-14}} = 1.38 \times 10^{-23}\,\text{T}$$

$$\text{T} = 1.67 \times 10^8\,\text{K}$$

The temperature in the interior of sum is about 2×10^7 K.

Therefore, very high temperature of the order 10^7 K are required for fusion reaction to take place.

87. Differentiate between nuclear fission and nuclear fusion. Which one of these processes produces energy (1) in nuclear reactor and (2) in the sun?

Ans : **Main 2005**

The differentiate between nuclear fission and nuclear fusion and nuclear are as follows :

	Nuclear Fission	**Nuclear Fission**
1.	Here a heavy nucleus when excited gets split up into two smaller nuclei of nearly comparable masses.	Here tow lighter nuclei fuse together to form a heavier nucleus.
2.	The conditions of high temperature and pressure are not necessary for its occurrence. If can be carried on the earth.	The conditions of extremely high pressure and temperature are necessary for its occurrence. So it cannot be easily carried in a laboratory.
3.	Neutrons are the link particles of this process.	Protons are the link particles of this process.
4.	It is a quick process.	It occurs in several steps. There is sufficient time gap between initial and final steps.
5.	The energy available per nucleon is small, about 0.85 MeV.	The energy available per nucleon is large, about 6.75 MeV.
6.	The energy obtained from a unit mass of a fissionable material is smaller than that obtained in case of fusion.	The energy obtained from a unit mass of a fusible material is large.
7.	It produces very harmful radioactive wastes.	The products of fusion are harmless.
8.	The stock of fissionable fusion is limited.	The fuel required for fusion is available in plenty.

1. Nuclear fission produces energy in a nuclear reactor.
2. Nuclear fusion produces energy in the sun.

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From the plot, it is concluded that

(a) The potential energy is minimum at a distance $r_0 (= 0.8\,\text{fm})$ which means that the force is attractive for distance larger than 0.8 fm and repulsive for the distance less than 0.8 fm between the nucleons.

(b) Nuclear forces are negligible when the distances between the nucleons is more than 10 fm.

77. (a) In the following nuclear reaction $n + {}^{235}_{92}\text{U} \longrightarrow {}^{144}_{Z}\text{Ba} + {}^{A}_{36}X + 3n$, assign the values of Z and A.

(b) If both the number of protons and the number of neutrons are conserved in each nuclear reaction, in what way is the mass converted into energy? Explain.

Ans : **Main 2015**

(a) $n + {}^{235}_{92}\text{U} \longrightarrow {}^{144}_{Z}\text{Ba} + {}^{A}_{36}X + 3n$

From law of conservation of atomic number,

$$0 + 92 = Z + 36$$

$$Z = 92 - 36 = 56$$

From law of conservation of mass number,

$$1 + 235 = 144 + A + 3 \times 1$$

$$A = 236 - 147 = 89$$

(b) (i) BE of ${}^{235}_{92}\text{U}$ < BE of $({}^{144}_{56}\text{Ba} + {}^{89}_{36}X)$ and due to difference in Binding energy of the nuclides. A large amount of the energy will released in the fission of ${}^{235}_{92}\text{U}$.

(ii) Mass number of the reactant and product nuclide are same but there is an actual mass defect. This difference in the total mass of the nuclei on both sides gets converted into energy, i.e., $\Delta E = \Delta\, mc^2$

78. How the size of a nucleus is experimentally determined? Write the relation between the radius and mass number of the nucleus. Show that the density of nucleus is independent of its mass number.

Ans : **Main 2004**

The size of the nucleus is experimentally determined using Rutherford's α-scattering experiment and the distance of closest approach and impact parameter.

The relation between radius and mass number of nucleus is

$$R = R_0 A^{1/3}$$

Where, $R_0 = 1.2\,\text{Fm}$

A = mass number

R = radius of nucleus

Nuclear density, $\rho = \dfrac{\text{Mass of nucleus}}{\text{Volume of nucleus}}$

$$= \frac{mA}{\frac{4}{3}\pi (R_0 A^{1/3})^3}$$

where, m = mass of each nucleon

Hence, $\rho = \dfrac{mA}{\frac{4}{3}\pi R_0^3 A}$

$$= \frac{m}{\frac{4}{3}\pi R_0^3}$$

From the above formula, it is clear that ρ does not depend on the mass number.

79. Explain how is fission an enormous source of energy per nuclear fission is about 200 MeV.

Ans : **Main 2017**

In a nuclear fission, the sum of the masses of the final products is less than the sum of the masses of the reactant components. The difference in masses, called mass defect, is converted into energy according to Einstein's mass-energy relationship $(E = mc^2)$. Thus an enormous amount of energy is released in a nuclear fission.

Suppose a nucleus with mass number $A = 240$ breaks into two fragments each of $A = 120$.

Then, Binding energy of per nucleon for $A = 240$ nucleus is about 7.6 MeV.

Binding energy of per nucleon for the two $A = 120$ fragments is about 8.5 MeV.

Hence, gain in B.E. per nucleon $\simeq 0.9\,\text{MeV}$.

Hence, the total gain in binding energy (by 240 nucleons)

$$\simeq 240 \times 0.9 = 216\,\text{MeV}$$

The disintegration energy of ${}^{235}_{92}\text{U}$ nucleus is about $(235 \times 0.9\,\text{MeV})$ 200 MeV. This energy appears in the form of kinetic energy of the fission products and as γ-rays. One kilogram of uranium will generate on fission $10^{14}\,\text{J}$ of energy. This is a very huge amount of energy.

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80. 1. The figure shows the plot of binding energy (BE) per nucleon as a function of mass number A. The letters A, B, C, D and E represent the positions of typical nuclei on the curve. Point out, giving reasons, the two process (in terms of A, B, C, D and E), one of which can occur due to nuclear fission and the other due to nuclear fusion.

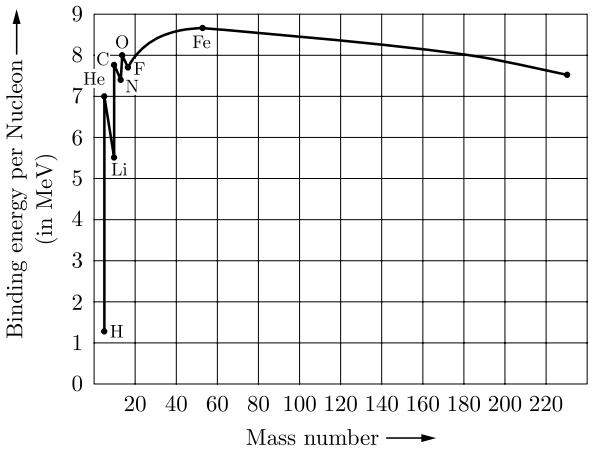
Nuclear Fission : When a heavy nucleus (A > 235 say) breaks into two lighter nuclei (nuclear fission), the binding energy per nuclear increases i.e. nucleons get more tightly bound. This implies that energy would be released in nuclear fission.

Nuclear Fusion : When two very light nuclei join to form a heavy nucleus, the binding energy per nucleon of fused. Heavier nucleus more than the binding energy per nucleon of lighter nuclei, so again energy would be released in nuclear fusion.

$$_1H^2 + {}_1H^2 \longrightarrow {}_2He^4 + 26\,MeV$$

92. Draw the graph showing the variation of binding energy per nucleon with the mass number for a large number of nuclei $2 < A < 240$. What are the main inferences from the graph? How do you explain the constancy of binding energy in the range $30 < A < 170$ using the property that the nuclear force is short-ranged? Explain with the help of this plot the release of energy in the processes of nuclear fission and fusion.

Ans : **Main 2008, 2005**



The variation of binding energy per nucleon versus mass number is shown in figure.

Inferences from Graph :

1. The nuclei having mass number below 20 and above 180 have relatively small binding energy and hence they are unstable.
2. The nuclei having mass number 56 and about 56 have maximum binding energy -5.8 MeV and so they are most stable.
3. Some nuclei have peaks, e.g., $_2He^4$, $_6C^{12}$, $_8O^{16}$; this indicates that these nuclei are relatively more stable than their neighbours.

(a) **Explanation of Constancy of Binding Energy :** Nuclear force is short ranged, so every nucleus interacts with its neighbours only, therefore binding energy per nucleon remains constant.

(b) **Explanation of Nuclear Fission :** When a heavy nucleus ($A \geq 235$ say) breaks into two lighter nuclei (nuclear fission), the binding energy per nucleon increases i.e., nucleons get more tightly bound. This implies that energy would be released in nuclear fission.

(c) **Explanation of Nuclear Fusion :** When two very light nuclei ($A \leq 10$) join to form a heavy nucleus, the binding is energy per nucleon of fused heavier nucleus more than the binding energy per nucleon of lighter nuclei, so again energy would be released in nuclear fusion.

93. What do you mean by binding energy of nucleus? Obtain an expression for binding energy. How binding energy per nucleon explains the stability of nucleus?

Ans : **SQP 2012,2016**

The binding energy of a nucleus may be defined as the energy required to break up a nucleus into its constituent protons and neutrons and to separate them to such a large distance that they may not interact with each other.

The binding energy may also be defined as the surplus energy which the nucleons give up by virtue of their attractions when they become bound together to form a nucleus.

If Δm is the mass defect of a nucleus, then its binding energy will be,

$$\Delta E_b = \Delta m \times c^2$$

Expression for Binding Energy : The nucleus $_Z^AX$ contains Z protons and $(A - Z)$ neutrons. It mass defect is,

$$\Delta m = Zm_p + (A - Z)\,m_n - m_N \qquad ...(1)$$

Where m_N is the nuclear mass of $_Z^AX$.

The binding energy of the nucleus is,

$$\Delta E_b = \Delta m \times c^2$$

$$= [Zm_p + (A - Z)\,m_n - m_N]\,c^2 \quad ...(2)$$

Now, in an atom the electrons are bound to the nucleus by electrostatic forces. So they have a binding energy of their own, which from the mass-energy equivalence is given by,

$$(\Delta E_b)_e = [(m_N + Zm_e) - m(_Z^AX)]\,c^2 \qquad ...(3)$$

where $m(_Z^AX)$ is the atomic mass. The binding energy of electrons ($\approx$ eV to keV) is negligible compared to the binding energy of nucleons ($\approx 10^3$ MeV). It will be a safe approximation to take,

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$$(\Delta E_b)_e = 0$$

$$m_N + Zm_e - m({}^A_Z X) = 0$$

$$m_N = m({}^A_Z X) - Zm_e$$

Thus, in terms of atomic mass the Eq. (2) becomes,

$$\Delta E_b = [Zm_p + (A-Z)\,m_n - m({}^A_Z X) + Zm_e]\,c^2$$

$$= [Z(m_p + m_e) + (A-Z)\,m_n - m({}^A_Z X)]\,c^2 \qquad ...(4)$$

But, $m_p + m_e = m_H$ = mass of a hydrogen atom

Hence, the Eq. (4) can be written in terms of m_H as,

$$\Delta E_b = [Zm_H + (A-Z)\,m_n - m({}^A_Z X)]\,c^2$$

Binding Energy Per Nucleon : The binding energy per nucleon is the average energy required to extract one nucleon from the nucleus. It is obtained by dividing the binding energy of a nucleus by its mass number. The expression for binding energy per nucleon can be written as,

$$\Delta E_{bn} = \frac{\Delta E_b}{A}$$

$$= \frac{[Zm_H + (A-Z)\,m_n - m({}^A_Z X)]\,c^2}{A}$$

The value of binding energy per nucleon of a nucleus gives a measure of the stability of that nucleus. Greater is the binding energy per nucleon of a nucleus, more stable is the nucleus.

NUMERICAL QUESTIONS

94. Calculate the energy equivalent of 1 g of substance.

Ans : Main 2010

$$m = 1\,\text{g} = 10^{-3}\,\text{kg}$$

$$c = 3 \times 10^8\,\text{ms}^{-1}$$

Equivalent energy, $E = mc^2 = 10^{-3} \times (3 \times 10^8)^2$

$$= 9 \times 10^{13}\,\text{J}$$

95. How many electron volts make up one joule?

Ans : SQP 2015

By definition, one electron volt is the energy gained by an electron, when accelerated through a potential difference of 1 volt, therefore

$$1\,\text{eV} = 1.602 \times 10^{-19}\,\text{C} \times 1\,\text{V}$$

$$= 1.602 \times 10^{-19}\,\text{J}$$

Hence, $1\,\text{J} = \frac{1}{1.602 \times 10^{-19}}\,\text{eV}$

$$= 6.242 \times 10^{18}\,\text{eV}$$

96. What is the value of radius of Ge^{70} : (Given $R_0 = 1.1\,\text{fm}$).

Ans : Comp 2004

Here, $A = 70$

$$R_0 = 1.1\,\text{fm}$$

$$R = R_0 A^{1/3}$$

$$= 1.1 \times (70)^{1/3}$$

$$= 1.1 \times 4.12$$

$$= 4.53\,\text{fm}$$

97. The atomic mass of Uranium ${}^{238}_{92}\text{U}$ is 238.0508 u while that of Thorium ${}^{234}_{90}\text{Th}$ is 234.0436 u and that of Helium ${}^{4}_{2}\text{He}$ is 4.0026 u, Alpha decay converts ${}^{238}_{92}\text{U}$ into ${}^{234}_{90}\text{Th}$ as shown

${}^{238}_{92}\text{U} \longrightarrow {}^{234}_{90}\text{Th} + {}^{4}_{2}\text{He} +$ energy.

Determine the energy released in this reaction.

Ans : Main 2014

Mass defect,

$$\Delta m = 238.0508 - (234.0436 - 4.0026)$$

$$= 0.0046\,\text{u}$$

As, energy $E = \Delta m \times c^2$

$$= 0.0046 \times 931.5 = 4.28\,\text{MeV}$$

98. Express 16 mg mass into equivalent energy in eV.

Ans : SQP 2007

Given, $m = 16\,\text{mg} = 16 \times 10^{-6}\,\text{kg}$

$$c = 3 \times 10^8\,\text{ms}^{-1}$$

Equivalent energy, $E = mc^2$

$$= 16 \times 10^{-6} \times (3 \times 10^8)^2\,\text{J}$$

$$= \frac{16 \times 10^{-6} \times (3 \times 10^8)^2}{1.6 \times 10^{-19}}\,\text{eV}$$

$$= 9 \times 10^{30}\,\text{eV}$$

99. Calculate the energy in fusion reaction:

$${}^{2}_{1}\text{H} + {}^{2}_{1}\text{H} \rightarrow {}^{3}_{2}\text{He} + {}_{0}n^{1}$$

Where, BE of ${}^{2}_{1}\text{H} = 2.23\,\text{MeV}$ and of ${}^{3}_{2}\text{He} = 7.73\,\text{MeV}$

Ans : Main 2011

Initial binding energy, $BE_1 = 2.23 + 2.23$

$$= 4.46\,\text{MeV}$$

Final binding energy, $BE_2 = 7.73\,\text{MeV}$

Hence, Energy released $= 7.73 - 4.46$

$$= 3.27\,\text{MeV}$$

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100. How much energy will be created if 1 g of matter is destroyed completely?

Ans : **Main 2010**

Mass, $m = 1\,g = 10^{-3}\,\text{kg}$

From energy-mass relation,

$$E = mc^2$$

Where, m = mass of the body

c = velocity of light

$= 10^{-3} \times (3 \times 10^8)^2$

$= 9 \times 10^{13}\,\text{J}$

Binding energy per nucleon α stability of the nucleus.

101. Fission of U-235 nucleus releases 200 MeV of energy. Calculate the fission rate (i.e., number of fissions per second) in order to produce a power of 320 MW.

Ans : **Main 2025**

Power obtained is given,

$$P = 320\ \text{MW} = 320 \times 10^6\,\text{W},$$

Energy released $= 200$ MeV

$$\text{Power, } P = \frac{E(\text{energy})}{t(\text{time})}$$

$$320 \times 10^6 = \frac{n \times 200 \times 1.6 \times 10^{-13}}{1}$$

Number of fissions per second

$$= n = 10^6 \times 10^{13} = 10^{19}$$

102. Calculate the minimum amount of energy which a gamma ray photon should have for the production of an electron and a positron pair.

Ans : **SQP 2022**

Rest mass of electron or positron $= M_0$ (for each)

From, Einstein's mass-energy equivalence relation, E

$$= m_0 c^2$$

$$= 9.1 \times 10^{-31} \times (3 \times 10^8)^2$$

$$= 8.2 \times 10^{-14}\,\text{J}$$

$$= \frac{8.2 \times 10^{-14}}{1.6 \times 10^{-19}}\,\text{eV} = 0.51 \times 10^6\,\text{eV}$$

$$= 0.51\,\text{MeV}$$

For pair production minimum energy

$$= 2 \times 0.51$$

$$= 1.02\,\text{MeV}$$

103. If the binding energy of the electron in a hydrogen atom is 13.6 eV. How much energy required to remove the electron from the first excited state of Li^{++}?

Ans : **SQP 2004**

Binding energy of electron in hydrogen atom, $E_H = 13.6$ eV.

Energy level of first excited state, $n = 2$.

Binding energy of hydrogen-like atom (Li^{++}) in n^{th} excited state,

$$E_n = \frac{E_H Z^2}{n^2}$$

$$= \frac{13.6 \times (3)^2}{(2)^2} = 30.6\,\text{eV}$$

104. (Where, $Z =$ Atomic mass of Li^{++} equal to 3) A nucleus with mass number, $A = 240$ and $BE/A = 7.6$ MeV breaks into two fragments each of $A = 120$ with $BE/A = 8.5$ MeV. Calculate the released energy.

Ans : **Main 2010**

Binding energy of nucleus with mass number 240,

$$BE_1 = 240 \times 7.6 = 1824\,\text{MeV}$$

Binding energy of two fragments,

$$BE_2 = 2 \times 120 \times 8.5$$

$$= 2040\,\text{MeV}$$

Hence,Energy released $= BE_2 - BE_1$

$$= (2040 - 1824)\,\text{MeV}$$

$$= 216\,\text{MeV}$$

105. When four hydrogen nuclei combine to form a helium nucleus, estimate the amount of energy in MeV released in this process of fusion. (Neglect the masses of electrons and neutrinos)

Given:

1. Mass of ${}_1^1\text{H} = 1.007825$ u
2. Mass of helium nucleus $= 4.002603$ u, $1\text{u} = 931\,\text{MeV/c}^2$

Ans : **Main 2003**

$$\text{Energy released} = \Delta m \times 931\,\text{MeV}$$

$$\Delta m = 4m({}_1^1\text{H}) - m({}_2^2\text{He})$$

Energy released,

$$Q = [4.m({}_1^1\text{H}) - m({}_2^4\text{He})] \times 931\,\text{MeV}$$

$$= [4 \times 1.007825 - 4.002603] \times 931\,\text{MeV}$$

$$= 26.72\,\text{MeV}$$

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CHAPTER 14

Electronics Device

SUMMARY

1. CLASSIFICATION OF SOLIDS ON THE BASIS OF THEIR CONDUCTIVITY

On the basis of the relative values of electrical conductivity (σ) and resistivity ($\rho = 1/\sigma$), the solids are broadly classified as:

1. **Metals :** Those solids which have high conductivity and very low resistivity. The value of conductivity for metals lies in between 10^2 to 10^8Sm^{-1} and of resistivity in between 10^{-2} to 10^8Sm^{-1} and of resistivity in between 10^{-2} to $10^{-8}\,\Omega\text{m}$.
2. **Insulators :** Those solids which have low conductivity and high resistivity. The value of conductivity for insulators lies between 10^{-11} to 10^{-19}Sm^{-1} and of resistivity between 10^{11} to $10^{19}\,\Omega\text{m}$.
3. **Semiconductors :** Those solids which have conductivity and resistivity intermediate to metals and insulators. The value of conductivity for semiconductors lies in between 10^5 to $10^{-6}\,\text{Sm}^{-1}$ and of resistivity between 10^{-5} to $10^6\,\Omega\text{m}$.

2. ENERGY BANDS OF SOLIDS OR BAND THEORY OF SOLIDS

In solids, closely spaced energy levels combine to form energy bands. The electrical conductivity of a solid depends on the
arrangement of electrons in these bands.

2.1 Valence Band

This band contains valence electrons. This band may be partially or completely filled with electrons. This band is never empty. Electrons in this band do not contribute to electric current.

2.2 Conduction Band

In this band, electrons are rarely present. This band is either empty or partially filled. Electrons in the conduction band are known as free electrons. These electrons contribute to the electric current.

2.3 Forbidden Energy Gap or Forbidden Band

The energy gap between the valence band and conduction band is known as forbidden energy gap or forbidden band. No electrons are present in this gap. It is a measure of energy band gap.

1. The minimum energy required for shifting electrons from valence band to conduction band is known as energy band gap.
2. If λ is the wavelength of radiation used in shifting the electron from valence band to conduction band, then energy band gap is,
$$E_g = h\upsilon = \frac{hc}{\lambda}$$
Where h is called Planck's constant and c is the speed of light.
3. The forbidden energy gap E_g in a semiconductor depends upon temperature.
4. Fermi energy is the maximum possible energy possessed by free electrons of a material at absolute zero temperature (i.e. 0 K).

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3. DIFFERENCES BETWEEN METALS, INSULATORS AND SEMICONDUCTORS ON THE BASIS OF BAND THEORY

According to band theory, solids are classified as metals, insulators, and semiconductors on the basis of the arrangement of electrons in the valence band and conduction band. The size of the energy gap between these bands determines the electrical conductivity of a material.

3.1 Metals

In metals either the conduction band is partially filled or conduction band and valence band partially overlap each other.

111. Calculate mass defect and binding energy per nucleon of $^{20}_{10}Ne$, given

Mass of $^{20}_{10}Ne = 19.992397$ u

Mass of $^{1}_{1}H = 1.007825$ u

Mass of $^{1}_{0}n = 1.008665$ u

Ans : **Main 2024, 2017**

In a nucleus of $^{20}_{10}Ne$

No. of protons $= 10$

No. of neutrons $= 20 - 10 = 10$

Total mass of 10 protons and 10 neutrons

$= 10m_p + 10m_n$

$= 10(m_p + m_n) = 10 \times (1.007825 + 1.008665)$

$= 20.1649$

Mass defect, $\Delta m = 20.1649 - 19.992397$

$= 0.172503$ u

Total binding energy $= 0.172503 \times 931$

$= 160.600293$ MeV

E_b per nucleon $= \dfrac{160.600293}{20}$

$= 8.03$ MeV/nucleon

112. Express one atomic mass unit in energy units, first in Joules and them in MeV. Using this, express the mass defect of $^{16}_{8}O$ in MeV.

Ans : **SQP 2018, 2006**

Given, $m = 1$ amu

$= 1.660565 \times 10^{-27}$ kg

$c = 2.9979 \times 10^{8}$ ms^{-1}

$E = mc^2$

$= 1.660565 \times 10^{-27} \times (2.9979 \times 10^{8})^2$ J

$= 1.4924 \times 10^{-10}$ J

$= \dfrac{1.4924 \times 10^{-10}}{1.602 \times 10^{-13}}$ MeV

[Since 1 MeV $= 1.602 \times 10^{-13}$ J]

$= 931.5$ MeV

The $^{16}_{8}O$ nucleus contains 8 protons and 8 neutrons.

Mass of 8 protons $= 8 \times 1.00727$

$= 8.05816$ amu

Mass of 8 neutrons $= 8 \times 1.00866$

$= 8.06928$ amu

Total mass $= 16.12744$ amu

Mass of $^{16}_{8}O$ nucleus $= 15.99053$ amu

Mass defect, $\Delta m = 0.13691$ amu

$\Delta E_b = 0.13691 \times 931.5$ MeV

$= 127.5$ MeV

113. Atomic weight of boron is 10.81 and it has two isotopes $_5B^{10}$ and $_5B^{11}$. What is the ratio of atomic weights of $_5B^{10}$ to $_5B^{11}$?

Ans : **Main 2013**

Atomic weight of boron $= 10.81$

Isotopes of boron $= {}_5B^{10}$ and $_5B^{11}$

Let, x be the atomic weight of isotope $_5B^{10}$ in boron.

Therefore, atomic weight of isotope $_5B^{11}$ in boron

$= (100 - x)$.

Atomic weight of boron

$= \dfrac{(x \times 10) + (100 - x) \times 11}{100}$

$= \dfrac{10x + 1100 - 11x}{100}$

$10.81 = \dfrac{1100 - x}{100}$

$x = 1100 - 1081 = 19$

Therefore value of isotope,

$_5B^{11} = 100 - x$

$= 100 - 19 = 81$

Therefore, ratio of atomic weights of $_5B^{10}$ to $_5B^{11}$

$= \dfrac{{}_5B^{10}}{{}_5B^{11}} = \dfrac{19}{81}$

or $_5B^{10} : {}_5B^{11} = 19 : 81$

CASE BASED QUESTIONS

114. India built its first nuclear reactor Apsara at Trombay, Maharashtra in the year 1956. It was used mainly to generate electric power. Nuclear reactors are around to produce radio-isotopes which are used in the fields of research, medicine, agriculture, etc. Unlike thermal power stations, nuclear power stations don't cause atmospheric pollution. Still, there is opposition to installing them as there is an that there may be a radiation leakage which can be harmful to the people living nearby.

(i) In a nuclear reactor, what is the function of cadmium rods?

(ii) In a nuclear reactor, which material is used as a moderator?

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(iii) Give any one balanced equation representing the nuclear fission reaction taking place in a nuclear reactor.

Ans : **2022 Sem-11**

(i) In a nuclear reactor, cadmium rod is used as control rod. It is used in nuclear reactors to control the rate of fission of uranium and plutonium.

(ii) Heavy water (D_2O) is used as moderator in nuclear reactors. Moderator is used to slow down the fast moving neutrons produced during the fission.

(iii) Nuclear fission

$$ {}^{1}_{0}n + {}^{235}_{92}\mathrm{U} \longrightarrow {}^{144}_{56}\mathrm{Ba} + {}^{89}_{36}\mathrm{Kr} + 3{}^{1}_{0}n $$

115. Mr. Ravi had been living in a small town with his family for many years. He decided to shift to a city when he learnt that a nuclear power plant would he built in his town. His son Prakash, who was a science teacher, did not agree with his father's decision.

Prakash explained to his father how mass defect during nuclear fission released energy. He assured his father that the authorities were taking all the possible safety measures to avoid any kind of nuclear mishap. Mr. Ravi understood the scientific explanation given by his son and decided not to shift to another place.

(i) What is the cause of energy generation of a nuclear reactor during nuclear fission?

(ii) Write one nuclear reaction for nuclear fission that takes place in a nuclear reactor.

(iii) Give the formula for the Energy generation that takes place in the nuclear reactor.

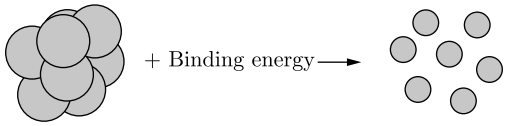
Ans : **Main 2022 Sem-II**

(i) Nuclear fission can be made a chain reaction that's for the power generation nuclear fission is used.

(ii) $ {}_{92}\mathrm{U}^{235} + {}_{0}n^{1} \longrightarrow {}_{38}\mathrm{Sv}^{94} + {}_{54}\mathrm{Xe}^{140} + 2\,{}_{0}n^{1} $

(iii) The energy released in the fission reaction can be calculated with Einstein's equation,which is $E = \Delta mc^2$.

116. An atomic nucleus is composed of protons and neutrons. The measurements using mass spectrometer have revealed that the mass of a stable nucleus is always less than the sum of the masses of its constituent protons and neutrons .The difference in the mass of a nucleus and its constituents is called mass defect, $\Delta m = Zm_p + (A - Z)m_n - M$. Using Einstein's mass energy relation. we express this mass difference in terms of energy as $\Delta E_b = \Delta mc^2$. This energy ΔE_b, is called the binding energy of the nucleus. This energy represents the surplus energy which the nucleons give up by virtue of their mutual attraction when they become bound together to form a nucleus. The value of binding energy per nucleon of a nucleus gives a measure of the stability of that nucleus. Greater is the binding energy per nucleon of a nucleus, more stable is the nucleus. In the mass number range $A = 30$ to 170, the binding energy per nucleon is nearly constant, about 8 MeV/nucleon.



Nucleus (smaller mass) — Separated nucleons (greater mass)

Answer the following questions from the above passage.

(i) Which instrument is used for measuring mass of the nuclei?

(ii) What is mass defect?

(iii) Why we calculate the binding energy per nucleon of nucleus?

(iv) The binding energy per nucleon is nearly constant for which mass number range?

Ans :

(i) Mass spectrometer is used for measuring mass of nuclei.

(ii) The difference in mass of a nucleus and its constituents is known as mass defect.

(iii) To know about the stability of the nucleus.

(iv) The binding energy per nucleon is nearly constant for mass number range $A = 30$ to 170, it is nearly about 8 MeV/nucleon.

117. The nucleus was first discovered in 1911 by Lord Rutherford and his associates by experiments on scattering of α-particles by atoms. He found that the scattering results could be explained, if atoms consists of a small, central, massive and positive core surrounded by orbiting electrons. The experimental results indicated that the size of the nucleus is of the order of 10-14 in and is thus 10000 times smaller than the size of atom.

(i) What is the ratio of mass of nucleus with mass of atom ?

(ii) if it is radius and A is mass number, then, plot the graph between log R and log A.

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(iii) What will be the ratio of masses of hydrogen, deuterium and tritium ?

(iv) Find the ratio of gold isotope silver isotope $^{197}_{79}\text{Au}$ and silver isotope $^{107}_{47}\text{Au}$.

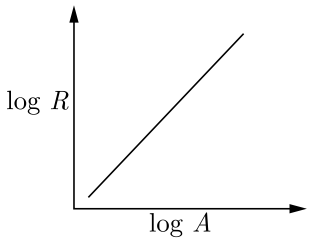
(v) What are the isotones ?

Ans :

(i) As 99.9% mass of atom is in nucleus

$$\frac{\text{mass of nucleus}}{\text{mass of atom}} = \frac{99.9}{100}$$
$$= \cdot 999 \approx 1.$$

(ii)



$$R = R_0 A^{1/3}$$

Taking log both sides

$$\log R = \log R_0 + \frac{1}{3}\log A$$

Compare it with

$$y = mx + C$$

(iii) As $^{1}_{1}\text{H}$, $^{2}_{1}\text{D}$, $^{3}_{1}\text{T}$, or $^{1}_{1}\text{H}$, $^{2}_{1}\text{H}$, $^{3}_{1}\text{H}$

Then ratio of masses = 1:2:3

(iv) $$\frac{R_1}{R_2} = \left(\frac{A_1}{A_2}\right)^{1/3} = \left(\frac{197}{107}\right)^{1/3} \approx 1.23$$

(v) Nuclides with same neutrons but different atomic numbers are isotones.

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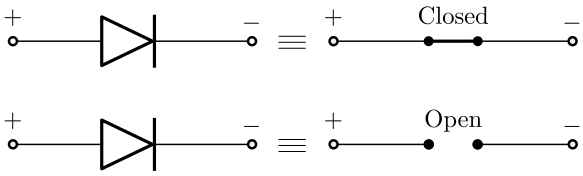
1. An ideal diode acts like an automatic switch.
2. In forward bias, it acts as a closed switch whereas in reverse bias it acts as an open switch as shown in the figure.

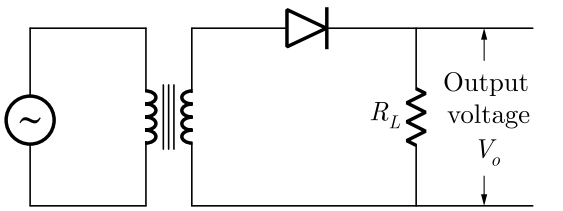


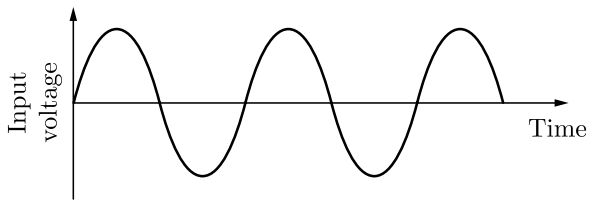
10. RECTIFIER

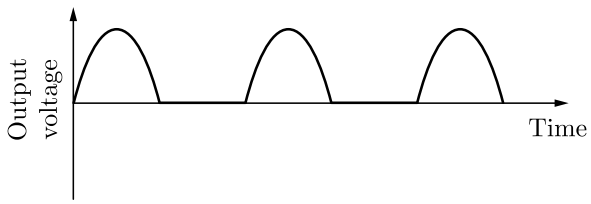
It is a device which converts AC voltage to DC voltage. Diode is used as a rectifier. Rectifier is based on the fact that, a forward bias p-n junction conducts and a reverse bias p-n junction does not conduct.

10.1 Half Wave Rectifier

Diode conducts corresponding to positive half cycle and does not conduct during negative half cycle, Hence, AC is converted by diode into unidirectional pulsating DC. This action is known as half-wave rectification.

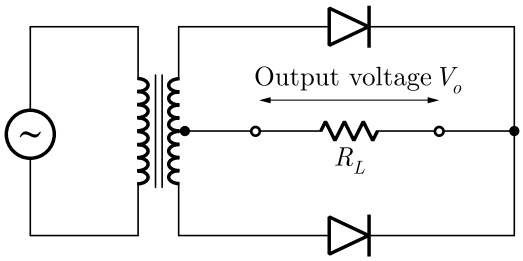


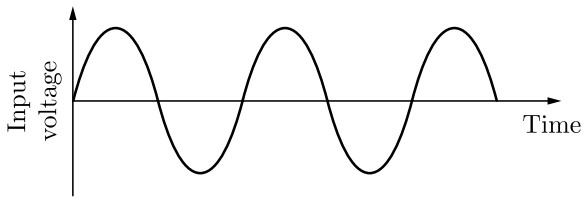


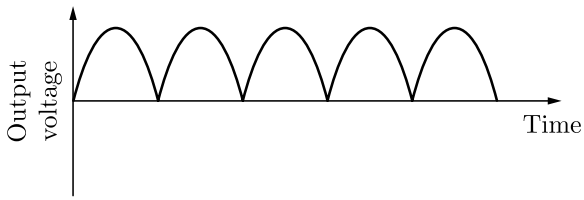


10.2 Full Wave Rectifier

The circuit diagram, input and output waveforms for a full wave rectifier are as shown in the figure.







10.3 Ripple Factor

The ripple factor is a measure of purity of the DC output of a rectifier and is defined as

$$r = \frac{\text{rms value of the components of wave}}{\text{average or dc value}}$$

$$= \sqrt{\left(\frac{I_{\text{rms}}}{I_{dc}}\right)^2 - 1}$$

11. SPECIAL PURPOSE p-n JUNCTION DIODES

Some junction diodes are designed for special applications in electronic devices. These diodes perform specific functions such as emitting light, detecting light or regulating voltage.

11.1 Light Emitting Diode (LED)

It converts electrical energy into light energy. It is a heavily doped p-n junction which operates under forward bias and emits spontaneous radiation.

1. The I-V characteristics of a LED is similar to that of Si junction diode. But the threshold voltages are much higher and slightly different for each colour. The reverse breakdown voltages of LEDs are very low, typically around 5 V.

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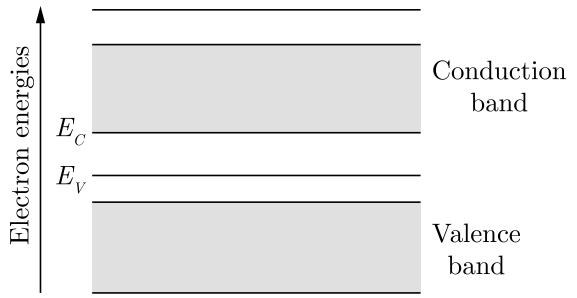
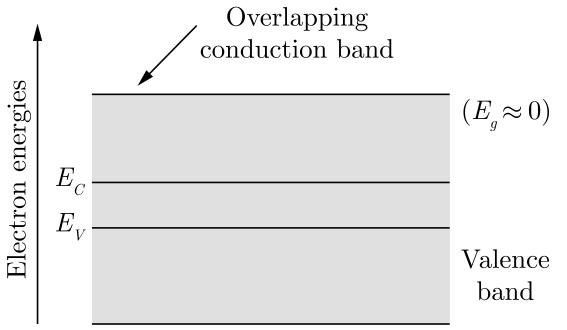
In metals, there is no forbidden energy gap between the valence and conduction bands.



(a)

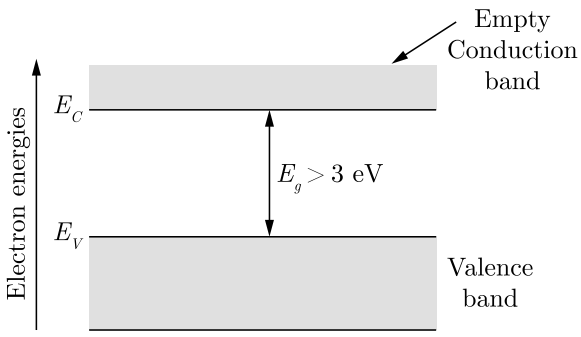


(b)

3.2 Insulators

In insulators, valence band is completely filled and conduction band is completely empty.

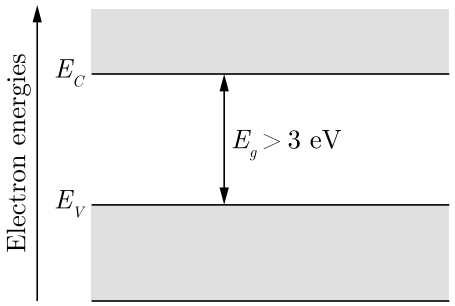
In insulators, there is a very wide forbidden energy gap between the valence and conduction bands. It is of the order of 5 eV or more.



3.3 Semiconductors

In semiconductors, valence band is completely filled and the conduction band is empty.

In semiconductors, there is a small forbidden energy gap between the valence and the conduction bands. It is of the order of 1 eV. For silicon, it is 1.1 eV and for germanium it is 0.72 eV.



At absolute zero, semiconductors behave as a perfect insulator.

Hole : It is a seat of positive charge which is produced when an electron breaks away from a covalent bond in a semiconductor. Hole has a positive charge equal to that of electron. Mobility of hole is smaller than that of electron.

4. INTRINSIC SEMICONDUCTOR

A pure semiconductor which is free from every impurity is known as intrinsic semiconductor. Germanium (Ge) and silicon (Si) are the important examples of intrinsic semiconductors.

1. In intrinsic semiconductor $n_e = n_h = n_i$ where n_e, n_h are number density of electrons in conduction band and number density of holes in valence band, n_i is the intrinsic carrier concentration.
2. When an electric field is applied across an intrinsic semiconductor, electrons and holes move in opposite directions so that total current (I) through the pure semiconductor is given by

$$I = I_e + I_h$$

Where I_e is the free electron current and I_h is the hole current.

3. **Effect of Temperature on Conductivity of Intrinsic Semiconductor :** An intrinsic semiconductor will behave as a perfect insulator at absolute zero.

With increasing temperature, the density of hole-electron pairs increases and hence the conductivity of an intrinsic semiconductor increases with increase in temperature. In other words, the resistivity (inverse of conductivity) decreases as the temperature increases.

The semiconductors have negative temperature coefficient of resistance.

5. DOPING

It is a process of deliberate addition of a desirable impurity to a pure semiconductor in order to increase its conductivity. The impurity atoms added are known as dopant.

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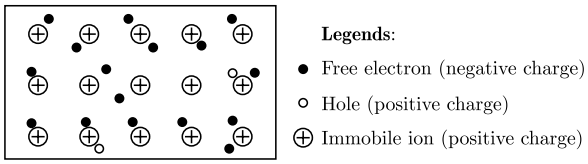
6. EXTRINSIC SEMICONDUCTOR

A doped semiconductor is known as extrinsic semiconductor. Extrinsic semiconductors are of two types:

6.1 n-Type Semiconductor

1. When a pure semiconductor of Si or Ge (tetravalent) is doped with a group V pentavalent impurities like arsenic (As), antimony (Sb), phosphorus (P) etc., we obtain a n-type semiconductor. The pentavalent impurity are known as donor atoms.
2. It is called n-type semiconductor because the conduction of electricity in such semiconductor is due to motion of electrons i.e. negative charges.
3. It is called donor type semiconductor, because the doped impurity atom donates one free electron to semiconductor for conduction.
4. In n-type semiconductor electrons are majority carriers and holes are minority carriers.
5. The representation of n-type semiconductor is as shown in the figure.



6. n-type semiconductor is neutral.
7. In n-type semiconductor,

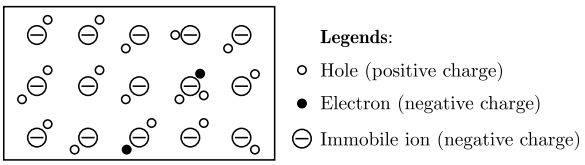
$$n_e \backsimeq N_d >> n_h$$

where, N_d is the density of donor atoms.

6.2 p-Type Semiconductor

When a pure semiconductor of Si or Ge (tetravalent) is doped with a group III trivalent impurities like aluminium (Al), boron (B), indium (In) etc., we obtain a p-type semiconductor. The trivalent impurity atoms are known as acceptor atoms.

1. It is called p-type because the conduction of electricity in such semiconductor is due to motion of holes i.e. positive charges.
2. It is called acceptor type semiconductor because doped impurity atom creates a hole in semiconductor which accepts the electron, resulting conduction in p-type semiconductor.
3. In p-type semiconductor, holes are majority carriers and electrons are minority carriers.
4. The representation of p-type semiconductor is as shown in the figure.



5. p-type semiconductor is neutral.
6. In p-type semiconductor

$$n_h \approx N_a >> n_e$$

where, N_a is the density of acceptor atoms.

7. MASS-ACTION LAW

Under thermal equilibrium, the product of the free negative and positive concentrations is a constant independent of the amount of donor and acceptor impurity doping. This relationship is known as the mass action law and is given by

$$n_e n_h = n_i^2$$

Where, n_e, n_h are number density of electrons and holes respectively and n_i is the intrinsic carriers concentration.

Electrical Conductivity in Semiconductor

The conductivity of the semiconductor is given by $\sigma = e(n_e \propto_e + n_h \propto_h)$ where μ_e and μ_h are the electron and hole densities, e is electronic charge.

1. The conductivity of an intrinsics semiconductor is,
   $\sigma_i = n_i e(\mu_e + \mu_h)$
2. The conductivity of n-type semiconductor is, $\sigma_n = eN_d\mu_e$.
3. The conductivity of p-type semiconductor is, $\sigma_p = eN_a\mu_h$.

8. p-n JUNCTION

When donor impurities are introduced into one side and acceptors introduced into one side and acceptors into the other side of a single crystal of an intrinsic semiconductor, a $p-n$ junction is formed. It is also known as junction diode. The most important characteristic of a $p-n$ junction is its ability to conduct current in one direction only. In the other (reverse) direction it offers very high resistance. It is symbolically represented by

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8.1 Depletion Region

In the vicinity of junction, the region containing the uncompensated acceptor and donor ions is known as depletion region. There is a depletion of mobile charges (holes and free electrons) in this region. Since this region has immobile (fixed) ions which are electrically charged it is also known as the space charge region. The electric field between the acceptor and the donor ions is known as a barrier. The physical distance from one side of the barrier to the other is known as the width of the barrier. The difference of potential from one side of the barrier to the other side is known as the height of the barrier.

1. For a silicon p-n junction, the barrier potential is about 0.7 V, whereas for a germanium p-n junction it is approximately 0.3 V.
2. The width of the depletion layer and magnitude of potential barrier depend upon the nature of the material of semiconductor and the concentration of impurity atoms. The thickness of the depletion region is of the order of one tenth of a micrometre.

8.2 Forward Biasing of a p-n Junction

When the positive terminal of external battery is connected to p-side and negative to n-side of p-n junction, then the p-n junction is said to be froward biased.

1. In forward biasing, the width of the depletion region decreases and barrier height reduces.
2. The resistance of the p-n junction becomes low in forward biasing.

8.3 Reverse Biasing of a p-n Junction

When the positive terminal of the external battery is connected to n-side and the negative terminal to p-side of a p-n Junction, then the p-n junction is said to be reverse biased.

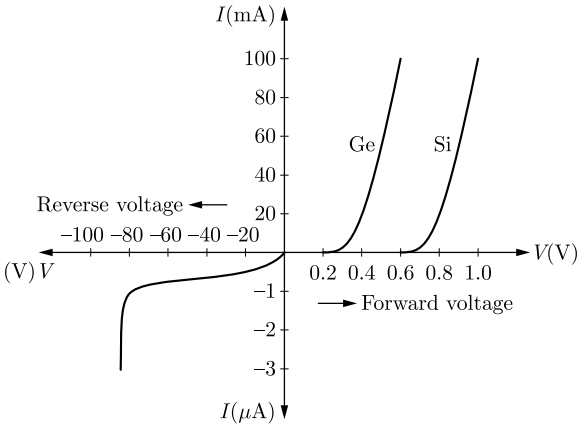
1. In reverse biasing, the width of the depletion region increases and barrier height increases.
2. The resistance of the p-n junction becomes high in reverse biasing.

8.4 Breakdown Voltage

A very small current flows through p-n junction, when it is reverse biased. The flow of the current is due to the movement of minority charge carriers. The reverse current is almost independent of the applied voltage. However, if the reverse bias voltage is continuously increased, for a certain reverse voltage, the current through the p-n junction will increase abruptly. This reverse bias voltage is thus known as breakdown voltage. There can be two different causes for the break down. One is known as zener breakdown and the other is known as avalanche breakdown.

I-V Characteristics of a p-n Junction

The I-V characteristics of a p-n junction do not obey Ohm's law. The I-V Characteristics of a p-n junction are as shown in the figure.

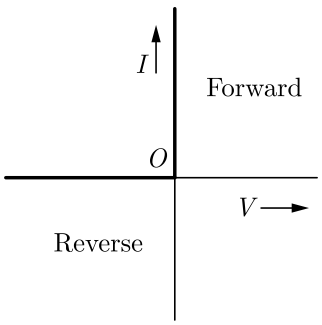


1. **Knee Voltage :** In forward biasing, the voltage at which the current starts to increase rapidly is known as cut-in or knee voltage. For germanium it is 0.3 V while for silicon it is 0.7 V.
2. **Dynamic Resistance :** It is defined as the ratio of a small change in voltage (ΔV) applied across the p-n junction to a small change in current ΔI through the junction.

$$r_d = \frac{\Delta V}{\Delta I}$$

9. IDEAL DIODE

A diode permits only unidirectional conduction. It conducts well in the forward direction and poorly in the reverse direction. It would have been ideal if a diode acts as a perfect conductor (with zero voltage across it) when it is forward biased, and as a perfect insulator (with no current-flows through it) when it is reverse biased. The I– V characteristics of an ideal diode as shown in figure.



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106. If radius of the $_{13}Al^{27}$ nucleus is estimated to be 3.6 fermi, What is the radius of $_{52}Te^{125}$ nucleus?

Ans : SQP 2011, 2010

Radius of nucleus $_{13}Al^{27}$ $R_1 = 3.6$ fermi

Mass number of $_{13}Al^{27}$ $A_1 = 27$ and

Mass number of $_{52}Te^{125}$ $A_2 = 125$

The radius of nucleus of an atom,

$$R = R_0 A^{1/3} \propto A^{1/3}$$

Therefore, $\frac{R_1}{R_2} = \left(\frac{A_1}{A_2}\right)^{1/3}$

$$= \left(\frac{27}{125}\right)^{1/3} = \frac{3}{5}$$

$$R_2 = \frac{5}{3} \times R_1$$

$$= \frac{5}{3} \times 3.6 = 6 \text{ fermi}$$

(where, $R_2 =$ Radius of nucleus $_{52}Te^{125}$)

107. In a certain star, three α-particles undergo fusion in a single reaction to form $^{12}_{6}C$ nucleus. Calculate the energy released in this reaction in MeV.

Given, $m(^{4}_{2}He) = 4.002604$ u and

$m(^{12}_{6}C) = 12.000000$ u

Ans : Comp 2013, 2009

Mass of three helium nucleus

$$_{2}He^{4} = 3 \times 4.002604 \text{ u} = 12.007812 \text{ u}$$

Mass of $_{6}C^{12} = 12.000000$ u

Mass defect, $\Delta m = 12.007812 - 12.000000$

$$= 0.007812 \text{ u}$$

Energy released, $E = \Delta m \times 931$

$$= 0.007812 \times 931$$

$$= 7.272972 \text{ MeV}$$

108. The nuclear mass of $^{56}_{26}$Fe is 55.85 amu. Calculate its nuclear density.

Ans : Main 2010

$$m_{Fe} = 55.85 \text{ amu}$$

$$= 55.85 \times 1.66 \times 10^{-27} \text{ kg}$$

$$= 9.27 \times 10^{-26} \text{ kg}$$

Nuclear radius,

$$R = R_0 A^{1/3}$$

$$= 1.1 \times 10^{-15} \times (56)^{1/3} \quad [\because A = 56]$$

$$\rho_{nu} = \frac{\text{Nuclear mass}}{\text{Nuclear volume}} = \frac{m_{Fe}}{\frac{4}{3}\pi R^3}$$

$$= \frac{9.27 \times 10^{-26}}{\frac{4\pi}{3} \times (1.1 \times 10^{-15})^3 \times 56}$$

$$= 2.9 \times 10^{17} \text{ kg m}^{-3}$$

109. Calculate binding energy of oxygen nucleus ($^{16}_{8}O$) from the data given below

Mass of a proton = 1.007825u

Mass of a neutron = 1.008665u

Mass of $^{16}_{8}O$ = 15.994915u

Ans : Main 2024

In the nucleus of $^{16}_{8}O$,

Number of protons = 8

Number of neutrons =16 – 8 = 8

Total mass of 8 protons and 8 neutrons

$$= 8m_p + 8m_n$$

$$= 8(1.007825) + 8 \times (1.008665)$$

$$= 8(1.007825 + 1.008665)$$

$$= 8 \times 2.01649 = 16.13192 \text{ u}$$

Mass defect,

$$\Delta m = 16.13192 - 15.994915$$

$$= 0.137005 \text{ u}$$

Total binding energy $= 0.137005 \times 931.5$

$$= 127.62 \text{ MeV}$$

110. Calculate the binding energy of an α-particle in MeV.

Given,

m_p (mass of proton) $= 1.007825$ amu

m_n(mass of neutron) $= 1.008665$ amu

Mass of He nucleus $= 4.002800$ amu

1 amu $= 931$ MeV

Ans : Main 2003

An α-particle contains 2 protons and 2 neutrons.

Mass of 2 protons $= 2 \times 1.007825$

$$= 2.015650 \text{ amu}$$

Mass of 2 neutrons $= 2 \times 1.008665$

$$= 2.017330 \text{ amu}$$

Total mass,

Mass of He nucleus $= 4.002800$ amu

Mass defect, $\Delta m = 0030180$ amu

Binding energy of α-particle

$$= 0.030180 \times 931$$

$$= 28.097 \text{ MeV}$$

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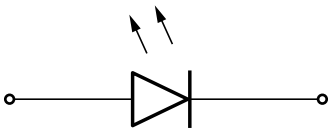
2. The semiconductor used for fabrication of visible LEDs must at least have a band gap of 1.8 eV. compound semiconductor gallium arsenide phosphide (GaAsp) is used for making LEDs of different colours. Ga As is used for making infrared LED.
3. The symbols of a LED is shown in the figure.

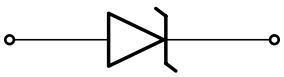


11.2 Solar Cell

It converts solar energy into electrical energy. A solar cell is basically a p-n junction generates emf when solar radiation falls on the p-n junction. It works on the same principle (photo voltaic effect) as the photo-diode, except that no external bias is applied and the junction area is kept large.

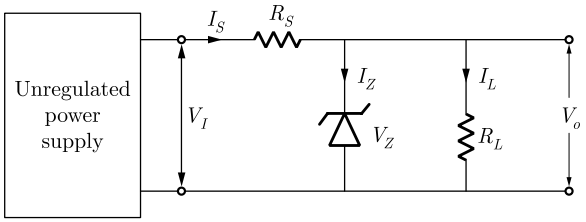
11.3 Zener Diode

It was invented by C. Zener. It is designed to operate under reverse bias in the breakdown region and is used as a voltage regulator. The symbol for Zener diode is shown in the figure.



Zener Diode as a Voltage Regulator

The circuit diagram for zener diode as a voltage regulator is shown in the figure below,



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OBJECTIVE QUESTIONS

1. With an increase in the temperature, electrical conductivity of a semiconductor
(a) decreases
(b) increases
(c) does not change
(d) first increases and then decreases

Ans : **Main 2023**

With increase in temperature, more electrons in a semiconductor gain enough energy to move from the valence band to the conduction band. This increases the number of charge carriers, so the electrical conductivity of the semiconductor increases. Thus (b) is correct option.

2. n - type semiconductor is that which has
(a) holes as majority carriers
(b) free electrons as majority carriers
(c) holes and free electrons equal in number
(d) trivalent element as an impurity

Ans : **SQP 2023**

An n-type semiconductor is formed by doping a pure semiconductor with a pentavalent impurity such as phosphorus or arsenic. This provides extra free electrons. Therefore, free electrons become the majority charge carriers, while holes are the minority carriers. Thus (b) is correct option.

3. In an extrinsic semiconductor, the number density of holes is $4 \times 10^{20} \mathrm{m}^{-3}$. If the number density of intrinsic carriers is $1.2 \times 10^{45}\,\mathrm{m}^{-3}$. The number density of electron in it is
(a) $1.8 \times 10^{9}\,\mathrm{m}^{-3}$ (b) $2.4 \times 10^{10}\,\mathrm{m}^{-3}$
(c) $3.6 \times 10^{9}\,\mathrm{m}^{-3}$ (d) $3.2 \times 10^{10}\mathrm{m}^{-3}$

Ans : **Main 2023**

The electron and hole concentration in a semiconductor in thermal equilibrium is given by,

$$n_e n_h = n_i^2$$
$$n_e = \frac{n_i^2}{n_h} = \frac{(1.2 \times 10^{15})^2}{4 \times 10^{20}}$$
$$= 0.36 \times 10^{10}$$
$$= 3.6 \times 10^{9}\,\mathrm{m}^{-3}$$

Thus (c) is correct option.

4. The formation of depletion region in a $p-n$ junction diode is due to
(a) movement of dopant atoms
(b) diffusion of both electrons and holes

NODIA

64. What is LED? Explain how radiations are given out by LED?

Ans : **Main 2005**

The LED means light emitting diode. It is a heavily doped p-n junction diode, which converts electrical energy into light energy.

When a p-n junction diode is forward biased, both the electrons and the holes move towards opposite side of the junction through it. As they cross the junction, the recombination of electrons and holes take place due to which energy is released at the junction in the form of electromagnetic radiation. (i.e. heat and light) This is because the electrons fall from a higher level in the conduction band to a lower level in the valence band. In case of Ge and Si diodes, the energy released is in the form of infrared radiation.

65. Distinguish between an intrinsic semiconductor and a p-type semiconductor. Give reason why a p-type semiconductor crystal is electrically neutral, although $n_h >> n_e$.

Ans : **Comp 2010**

The difference between intrinsic semiconductor and a p-type semiconductor are as follows :

	Intrinsic semiconductor	**p-type semiconductor**
(i)	It is a semiconductor in pure form.	It is a semiconductor doped with p-type like Al, in impurity.
(ii)	Intrinsic charge carriers are electrons and holes with equal concentration.	Majority charge carries are holes and minority charge carriers are electrons.
(iii)	Current due to charge carriers is feeble (of the order of μA).	Current due to charge carriers is significant (of the order of mA).

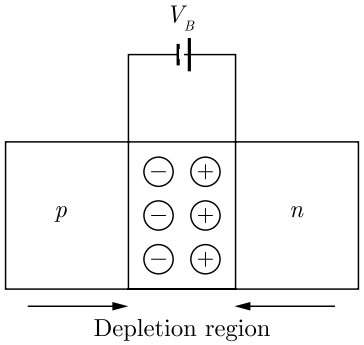
p-type semiconductor is electrically neutral because every atom, whether it is of pure semiconductor (Ge or Si) or of impurity (Al) is electrically neutral.

66. Name the important process that occurs during the formation of a $p-n$ junction. Explain briefly, with the help of a suitable diagram, how a $p-n$ junction is formed. Define the term 'barrier potential'.

Ans : **Main 2016, 2011**

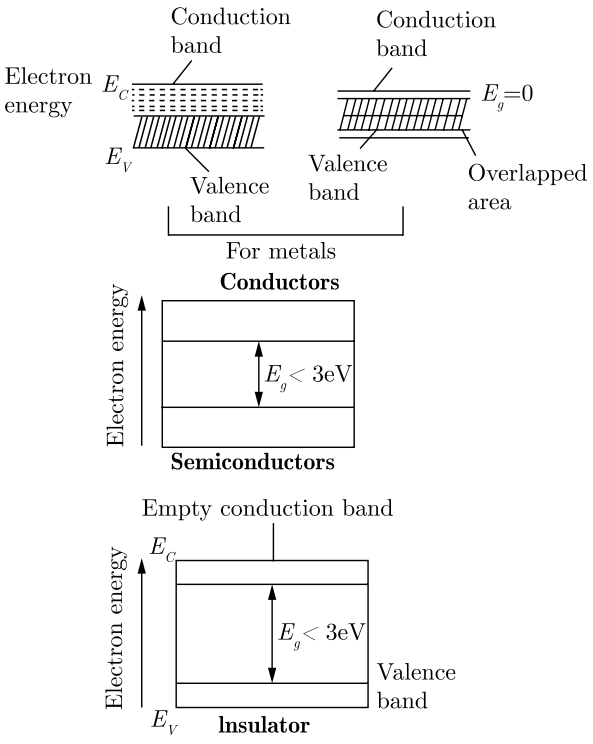
Potential Barrier : During the formation of a $p-n$ junction, the electrons diffuse from n-region. This forms recombination of charge carriers. In this process, immobile positive ions are collected at a junction toward n-region and negative ions at a junction toward p-region. This causes a potential difference across the unbiased junction. This is called potential barrier.

Depletion Region : It is a layer formed near the junction which is devoid of free charge carriers. Its thickness is about 1μm.



67. Draw energy band diagrams of conductors, semiconductors and insulators.

Ans : **Main 2007, 2000**



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Ans : SQP 2014

With the increase of temperature, the excitation of charge carriers (i.e., electrons) increases. It increases the concentration of charge carriers and conductivity. As a result of this, there is a small decrease in the width of forbidden gap. Thus (a) is correct option.

12. A pure semiconductor behaves slightly as a conductor at

(a) low temperature (b) high temperature

(c) room temperature (d) both (a) and (b)

Ans : SQP 2013

At room temperature, a few electrons in valence band acquire energy greater than the forbidden energy gap and jump to the conduction band. Therefore at room temperature, a pure semiconductor behaves slightly as a conductor.

Thus (c) is correct option.

13. When the conductivity of a semiconductor is only due to breaking of covalent bonds, the semiconductor is called

(a) extrinsic (b) intrinsic

(c) n-type (d) p-type

Ans : Main 2007

In an intrinsic or pure semiconductor, the charge carriers (i.e., electrons and holes) are created due to breaking of covalent bonds. Therefore conductivity of an intrinsic semiconductor is only due to breaking of covalent bonds. Thus (b) is correct option.

14. In some substances, charge can flow at ordinary temperature, but not at very low temperatures. These substances are called

(a) conductors (b) insulators

(c) dielectrics (d) semiconductors

Ans : Comp 2003

In semiconductor, charge can flow at ordinary temperature. And its resistance increases with the decrease in temperature. Therefore at absolute zero temperature, a semiconductor behaves as an insulator.

Thus (d) is correct option.

15. At 0 K temperature, a p-type semiconductor

(a) does not have any charge carrier

(b) has few holes and few free electrons

(c) has few holes but no free electron

(d) has equal no. of holes and free electrons

Ans : SQP 2001

At 0 K temperature, a p-type semiconductor behaves as an insulator, because it has a few holes in its valence band. But there is no free electrons in this state.

Thus (c) is correct option.

16. To obtain a p-type semiconductor, germanium atom must be doped with

(a) arsenic (b) antimony

(c) indium (d) phosphorus

Ans : Main 2024

To obtain a p-type semiconductor, germanium atom must be doped with a trivalent impurity atom.

Since indium is a trivalent impurity atom, therefore when tetravalent germanium is doped with trivalent impurity, we obtain a p-type semiconductor.

Thus (c) is correct option.

17. To a germanium sample, traces of gallium are added as an impurity. The resultant sample would behave like a/an

(a) conductor

(b) insulator

(c) p-type semiconductor

(d) n-type semiconductor

Ans : SQP 2015, 2011

Gallium is a trivalent impurity atom. Therefore when the traces of gallium are added to a germanium sample as an impurity, we obtain a p -type semiconductor. Thus (c) is correct option.

18. Which of the following, when added as an impurity atom in the silicon, produces n-type semiconductor ?

(a) phosphorous

(b) aluminium

(c) magnesium

(d) None of these

Ans : Main 2009

Phosphorous is a pentavalent impurity atom. Therefore, when tetravalent silicon atom is doped with a pentavalent impurity atom, it produces an n-type semiconductor.

Thus (a) is correct option.

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19. When germanium atoms is doped with equal no. of antimony atoms, we get a/an

(a) superconductor

(b) p-type semiconductor

(c) n-type semiconductor

(d) intrinsic semiconductor

Ans : **Main 2006**

Antimony is a pentavalent element having five valence electrons. When germanium is doped with antimony atoms, four electrons form covalent bonds with germanium atoms and one extra electron becomes free. These free electrons increase electrical conductivity, making the semiconductor an n-type semiconductor.r.

Thus (c) is correct option.

20. The n-type semiconductors are obtained, when germanium is doped with

(a) arsenic (b) phosphorus

(c) antimony (d) any one of these

Ans : **SQP 2004**

Arsenic, phosphorous and antimony are pentavalent impurity atoms.

Therefore n-type semiconductors are obtained when tetravalent germanium atom is doped with any one of them.

Thus (d) is correct option.

21. The potential barrier, in the depletion layer, is due to

(a) ions (b) holes

(c) electrons (d) forbidden band

Ans : **Comp 2017, 2010**

The recombination of free and mobile electrons and holes produce the narrow region at the junction called depletion layer.

It is so named because only positive ions are present there which are not free to move.

Thus (a) is correct option.

22. In a p–n junction photo cell, the value of the photo-electromotive force, produced by monochromatic light is proportional to

(a) voltage applied at the p–n junction

(b) intensity of light falling on the cell

(c) barrier voltage at the p–n junction

(d) frequency of light falling on the cell

Ans : **Comp 2008**

In a p–n junction photo cell, the value of photo-electromotive force produced by monochromatic light is proportional to the intensity of light falling on the cell.

Thus (b) is correct option.

23. The region with free electrons and holes in a p–n junction diode is

(a) p-region (b) n-region

(c) junction (d) depletion region

Ans : **Main 2013**

In a p–n junction diode, excess electrons from the n-region cross over to the p-region across the junction, which are neutralised by the holes and give a charge-less region called depletion region.

Thus (d) is correct option.

24. In a p–n junction diode, the holes are due to

(a) protons

(b) neutrons

(c) extra electrons

(d) missing of electrons

Ans : **Main 2025**

In a p–n junction when an electron leaves the n -region, a positive charge is left behind it, and a hole is created.

Thus holes are formed due to missing of electrons.

Thus (d) is correct option.

25. When the p-end of the p–n junction is connected to the negative terminal and the n-end to the positive terminal of the battery, then p–n junction behaves like a/an

(a) insulator (b) conductor

(c) semiconductor (d) superconductor

Ans : **SQP 2007**

When p-end of p–n junction is connected to the negative terminal and n-end to the positive terminal of the battery, then p–n junction is reverse biased, which offers high resistance. Therefore p–n junction behaves like an insulator.

Thus (a) is correct option.

26. The peak voltage in the output of a half wave diode rectifier fed with a sinusoidal signal without filter is 10 V.The DC component of the output voltage is

(a) $\frac{20}{\pi}$V (b) $\frac{10}{\sqrt{2}}$V

(c) $\frac{10}{\pi}$V (d) 10 V

NODIA

Ans : **Main 2010**

Peak voltage in the output of a half wave diode rectifier,

$$V_0 = 10 \text{ Volt}$$

DC component of the output voltage,

$$V_{dc} = \frac{I_0}{\pi}$$

$$= \frac{10}{\pi} \text{ Volt}$$

Thus (c) is correct option.

27. A rectifier converts

(a) light energy into electrical energy

(b) high frequency into low frequency

(c) alternating current into direct current

(d) mechanical energy into electric energy

Ans : **SQP 2024**

A rectifier is a device which converts an alternating current (or voltage) into direct current (or voltage).The process of converting alternating current into direct current is called rectification.

Thus (c) is correct option.

28. A p–n junction is used as a/an

(a) rectifier (b) amplifier

(c) oscillator (d) modulator

Ans : **Main 2003**

A rectifier is a device which converts an alternating current (or voltage) into direct current (or voltage). We also know that when an alternating e.m.f. signal is applied across a p–n junction, it permits large current during forward bias, and no current during reverse bias. That is why, a p–n junction is used as rectifier.

Thus (a) is correct option.

29. In comparison to a half wave rectifier, the full wave rectifier gives lower

(a) efficiency

(b) average current

(c) average output voltage

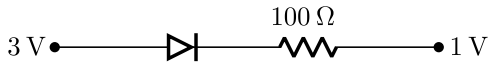
(d) none of these

Ans : **SQP 2012, 2005**

Efficiency, average current as well as average output voltage in case of full wave rectifier are higher as compared to half wave rectifier.

Thus (d) is correct option.

30. Assuming that the p–n junction diode shown in the figure is ideal, the current through the diode is



(a) 0.02 A (b) 2 A

(c) 0.2 A (d) 20 A

Ans : **Comp 2016**

Potential at one end, $V_1 = 3 \text{ Volt}$

Potential at other end, $V_2 = 1 \text{ Volt}$

External resistance, $R = 100\,\Omega$

change in potentials,

$$\Delta V = V_1 - V_2$$

$$= 3 - 1 = 2 \text{ Volt}$$

Since the p–n junction diode offers zero resistance when it is ideal, therefore current through the diode,

$$I = \frac{\Delta V}{R} = \frac{2}{100} = 0.02 \text{ A}$$

Thus (a) is correct option.

ASSERTION AND REASON

DIRECTION : These questions consist of two statements, each printed as Assertion and Reason. While answering these questions, you are required to choose any one of the following five responses.

31. **Assertion :** The resistivity of a semi-conductor increases with temperature.

Reason : The atoms of semi-conductor vibrate with larger amplitude as higher temperatures thereby increasing its resistivity.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **Main 2018**

The resistivity of semiconductor decreases with increase in temperature as more electrons jump into conduction band increasing its conductivity.

Thus (d) is correct option.

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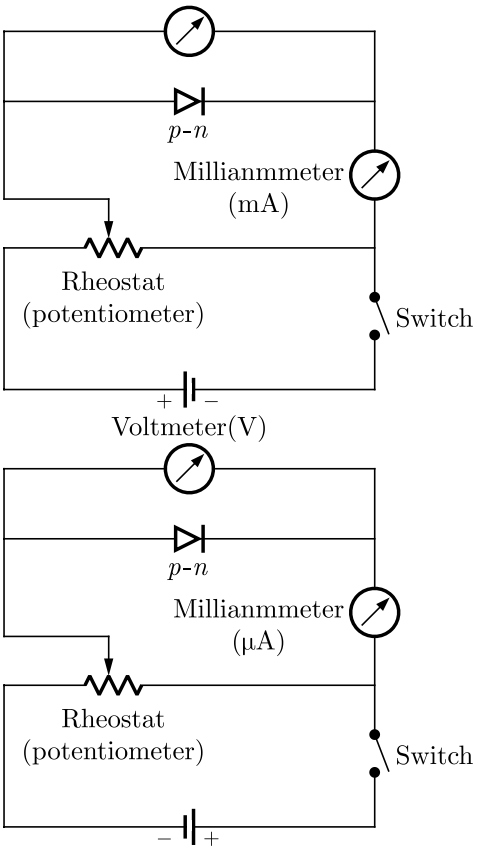
53. Draw circuit diagrams to illustrate forward biasing and reverse biasing of a diode.

Ans : **Main 2000**



TWO MARKS QUESTIONS

54. With reference to semiconductor Physics, answer the following questions.

(i) What is meant by "forbidden band" of energy levels?

(ii) In which material "forbidden band" is absent?

Ans : **Main 2023**

(i) The minimum energy required for silting electrons from valence bond to conduction band is called energy band gap (E_g).

(ii) Insulators

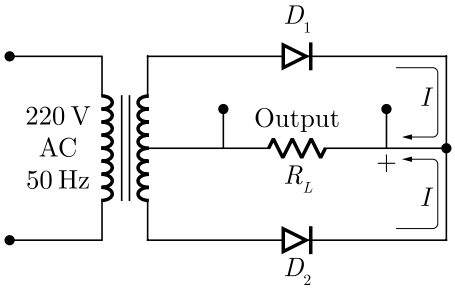
55. What happens when a forward bias is applied to a p-n-junctions.

Ans : **SQP 2019, 2013**

When a forward bias is applied to p-n-junction, the forward voltage opposes the potential barrier, due to which the potential barrier and the width of the depletion layer decreases. Under the effect of external electric field, hole in the p-region and electrons in the n-region, both move towards the junction and a forward current of milliampere order flows in circuit.

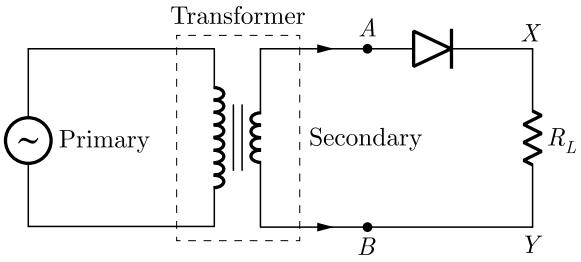
56. Draw the circuit diagram to explain in the working of a full wave p-n junction rectifier.

Ans : **Main 2020**



57. Draw a labelled circuit diagram of a half-wave rectifier

Ans : **Main 2019**



58. Answer the following giving reasons :

(i) A $p-n$ junction diode is damaged by a strong current.

(ii) Impurities are added in intrinsic semiconductors.

Ans : **Main 2023**

(i) When a strong current passes through the semiconductor it heats up the crystal and covalent bonds are broken. Hence, because of excess number of free electrons it behaves like a conductor.

(ii) If some impurity is added to intrinsic semiconductor it will increase the concentration or density of charge carriers (either holes or electrons) and which in turn increases its conductivity.

59. Explain the following terms

(i) Intrinsic semiconductor.

(ii) Extrinsic semiconductor.

NODIA

42. To convert a pure semiconductor into n-type semiconductor, what type of impurity is added to it?

Ans : **Main 2013**

A pentavalent impurity is to be added to form n-type semiconductor whose majority carriers are electrons. e.g. Sb, P or As is added to Ge (or Si).

43. What is mean by a full wave rectifier?

Ans : **Main 2010**

A full wave rectifier is a device which converts both the halves (negative and positive) of an AC input voltage into a unidirectional pulsating output voltage.

44. What is meant by energy gap in solids?

Ans : **Main 2007**

The energy difference between valence band and conduction band is called energy gap in solids.

i.e. $E_g = E_c - E_v$

45. What is the advantage of an LED bulb over the filament electric bulb?

Ans : **Main 2020, 2017**

LED's are small, solid light bulbs which are extremely energy efficient and long lasting, so these devices are more rugged and durable than traditional filament electric bulbs.

46. How can an n-type semiconductor be obtained from a pure crystal of germanium?

Ans : **Main 2025**

An n-type semiconductor can be obtained from a pure germanium crystal by adding pentavalent impurity atom to a Ge crystal. Thus increasing number of free electron.

47. Explain why the electrical conductivity of a pure semiconductor increases on heating?

Ans : **Main 2005**

The conductivity of a semiconductor increases with rise in temperature, because of increase in number of free electrons in conduction band of semiconductor material.

48. What happens to the width of depletion layer of a $p-n$ junction when it is (i) forward biased, (ii) reverse biased?

Ans : **SQP 2020**

(i) When forward biased, the width of depletion layer decreases.

(ii) When reverse biased, the width of depletion layer increases.

49. State any one difference between energy band diagram of conductors and that of insulators.

Ans : **Main 2020**

In conductors, the energy gap between valence band and conduction band is zero mostly, they overlap. But in insulators, the energy gap is very high so that it is impossible to get the electrons into the conduction band.

50. What are energy bands in solids?

Ans : **Main 2002**

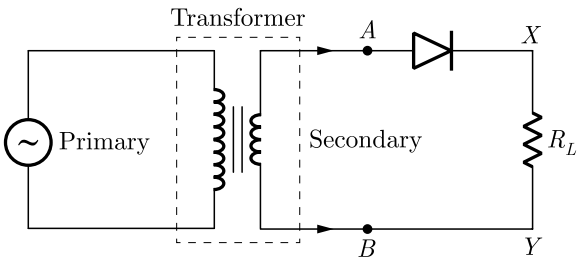
On the basis of band theory of solids, there are two energy bands.

(i) Conduction band which is responsible for conduction of electricity.

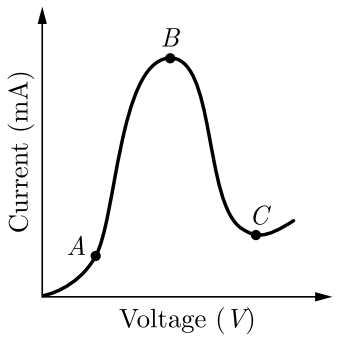
(ii) Valence band which is present just below the conduction band and always have electrons.

51. Draw the circuit diagram of a half-wave rectifier using a p-n junction diode.

Ans : **Main 2007**



52. The graph shown in the figure represents a plot of current versus voltage for a given semiconductor. Identify the region at which the semiconductor has a negative resistance.



Ans : **Main 2021, 2015**

Resistance of a material can be found out by the slope of the curve V versus I. Part BC of the curve shows the negative resistance as with the increase in current and decrease in voltage.

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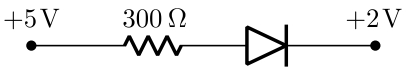
32. **Assertion :** The value of current through p-n junction in the given figure will be 10 mA.



Reason : In the above figure, p-side is at higher potential than n-side.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **SQP 2014**

The p-side of the junction diode is at a higher potential than the n-side. So p-n junction is forward biased. Hence a current flows through it and is given by

$$I = \frac{V}{R} = \frac{5-2}{300}$$
$$= 10^{-2}\,\text{A}$$
$$= 10\,\text{mA}$$

Thus (b) is correct option.

33. **Assertion :** The number of electrons in a p-type silicon semiconductor is less than the number of electrons in a pure silicon semiconductor at room temperature.

Reason : It is due to law of mass action.

(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) The Assertion is correct but Reason is incorrect.

(d) Both the Assertion and Reason are incorrect.

Ans : **SQP 2011**

We know that $n_e n_h = h_i^2$

This formula is based on law of mass action. In p -type semiconductor $n_h > n_i$. So, $m_e < n_i$.

Thus (a) is correct option.

ONE MARK QUESTIONS

34. Name the majority charge carriers in n-type semiconductor.

Ans : **Main 2015**

In n - type semiconductor, the electrons are the majority charge carriers.

35. What is meant by doping?

Ans : **Main 2010**

The process of adding impurity to an intrinsic semiconductor in controlled manner is called doping.

36. What is the change in the resistance of the semiconductor with increase in temperature?

Ans : **Main 2019, 2012**

The resistance of semiconductor decreases with rise in temperature.

37. What is meant by a rectifier?

Ans : **Main 2024**

Rectifier is a semiconductor device used to convert Alternating Current (AC) to Direct Current (DC).

38. In semiconductors, what is meant by "doping"?

Ans : **SQP 2023**

The process of adding impurity to an intrinsic semiconductor in a controlled manner is called doping.

39. What type of semiconductor is obtained when a crystal of silicon is doped with a trivalent element?

Ans : **Main 2023**

When a trivalent impurity is doped in an intrinsic semiconductor (silicon), then we get a p-type semiconductor.

40. In which of the solids (semiconductors, conductors or insulators), do conduction band and valence band overlap?

Ans : **Main 2009**

In conductors, conduction band and valence band overlap with each other.

41. State how a p-type semiconductor will be obtained from a pure crystal of a semiconductor.

Ans : **Main 2022 Sem-II**

To obtain a p-type semiconductor, pure silicon is dipped with a trivalent impurity like indium, aluminium or boron.

NODIA

Ans : **Main 2022 Sem-II**

(i) A pure semiconductor which is free from every impurity is known as intrinsic semiconductor. Germanium (Ge) and silicon (Si) are the important examples of intrinsic semiconductors..

(ii) A doped semiconductor is known as extrinsic semiconductor. Extrinsic semiconductors are of two types:

1. N-type semiconductor
2. P-type semiconductor

60. Distinguish between 'Intrinsic' and 'Extrinsic' semiconductors?

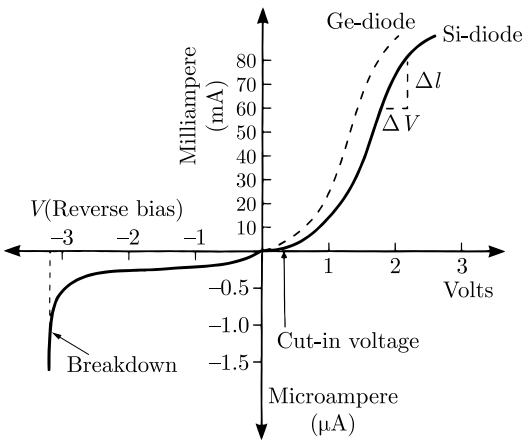
Ans : **SQP 2015**

The differences between intrinsic and Extrinsic semiconductor are as follows :

	Intrinsic semiconductor	**Extrinsic semiconductor**
1.	It is a pure semiconductor material with no impurity atoms in it.	It is prepared by doping a small quantity of impurity atoms to the pure semiconductor.
2.	The number of free electrons in the conduction band and the number of holes in valence band is exactly equal.	The number of free electrons and holes is never equal. There is an excess of electrons in n-typed semiconductors and excess of holes in p-type semiconductors.

61. Draw the voltage-current characteristic curve of a diode and mark its important parameter.

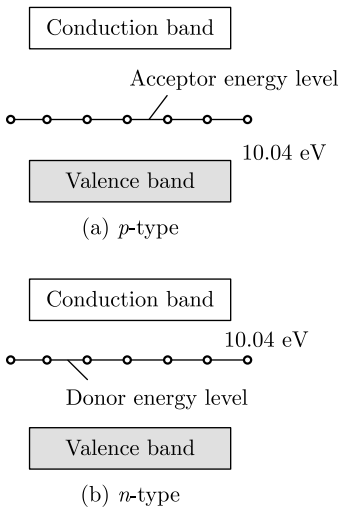
Ans : **Main 2014**



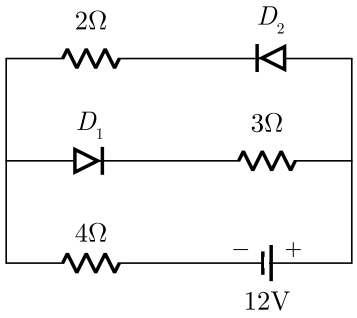
62. Draw energy band diagram of n-typed and p -typed semiconductor at temperature $T > 0\,\text{K}$. Mark the donor and acceptor energy level with their energies.

Ans : **SQP 2025**

The required energy band diagram is shown below.



63. The circuit shown in the figure has two oppositely connected ideal diodes connected in parallel. Find the current flowing through each diode in the circuit.



Ans : **Main 2013, 2010**

(i) Diode D_1 is reverse biased, so it offers an infinite resistance. So, no current flows in the branch of diode D_1.

(ii) Diode D_2 is forward biased, and offers no resistance in the circuit. So, current in the branch.

$$I = \frac{V}{R_{eq}}$$
$$= \frac{12\text{V}}{2\Omega + 4\Omega}$$
$$= 2\text{A}$$

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(c) drift of electrons only

(d) drift of holes only

Ans : SQP 2023

In a p–n junction diode, when the p-type and n-type semiconductors are joined, electrons from the n-side diffuse into the p-side and holes from the p-side diffuse into the n-side due to concentration difference. This diffusion leaves behind immobile ions near the junction, forming the depletion region.

Thus (b) is correct option.

5. A semiconductor is cooled from T_1 K to T_2 K, then its resistance will

(a) increase

(b) decrease

(c) remain constant

(d) first decrease then increase

Ans : Main 2018, 2015

Actually resistivity depends upon the temperature in such way:

$$\rho = \rho_0[1 + \alpha(T_f - T_i)]$$

Where, α = Coefficient of resistivity

In case of semiconductor 'α' be negative. Hence if we increases the temperature then resistivity will be decreases, it means resistance will be decreases. Here, semiconductor is cooled, means temperature decreases then, resistivity increases and hence, resistance increases.

Thus (a) is correct option.

6. For n-type Germanium, impurity doped in Germanium is

(a) Trivalent (b) Tetravalent

(c) Pentavalent (d) None of these

Ans : Comp 2017

n-type semiconductor is obtained by doping the tetravalent semiconductor Si (or Ge) with pentavalent impurities such as As, P or Sb group V of the periodic table.Thus (c) is correct option.

7. Diode is used as

(a) An amplifier (b) An oscillator

(c) A modulator (d) A rectifier

Ans : SQP 2017

A diode is a semiconductor device that allows electric current to flow in only one direction and blocks it in the reverse direction. Because of this property, it is widely used as a rectifier in electronic circuits. A rectifier converts alternating current (AC), which changes direction continuously, into direct current (DC), which flows in one direction. Diodes are commonly used in power supplies, chargers, radios, and many electronic devices.

Thus (d) is correct option.

8. The majority current-carrier in p-type semiconductor is

(a) electron (b) hole

(c) photon (d) proton

Ans : Main 2025

A p-type semiconductor is formed by doping a pure semiconductor with a trivalent impurity such as boron or aluminium. This creates vacancies called holes in the crystal structure. These holes act as positive charge carriers and become the majority carriers, while electrons are the minority carriers.

Thus (b) is correct option.

9. The state of energy of the valence electrons, when the temperature is raised or when electric field is applied, is called

(a) valence band (b) conduction band

(c) forbidden band (d) none of these

Ans : Main 2011

State of energy of the valence electrons, when the temperature is raised or electric field is applied, is called conduction band.

An increase in the conduction band increases conductivity of the metal.Thus (b) is correct option.

10. The impurity atom that should be added to the germanium to make it an n-type semiconductor is

(a) iodine (b) indium

(c) arsenic (d) aluminium

Ans : Main 2009, 2005

To make germanium an n-type semiconductor, a pentavalent impurity is added. Arsenic is a pentavalent element having five valence electrons. Four electrons form bonds with germanium atoms, while the fifth electron becomes free for conduction. Thus, free electrons become the majority charge carriers in the semiconductor.

Thus (c) is correct option.

11. With the increase of temperature, width of the forbidden gap

(a) decreases (b) increases

(c) remains same (d) becomes zero

NODIA

THREE MARKS QUESTIONS

68. With reference to semiconductor physics, define the following terms.
(i) Doping
(ii) Depletion region

Ans : Main 2022 Sem-II

(i) The process of adding impurity to anintrinsic semiconductor in a controlled manner is called doping.

(ii) The region on either side of the junction which becomes depleted (free) from the mobile charge carriers is called depletion region.

69. With reference to a semiconductor diode, explain the terms
(i) Depletion region
(ii) Potential barrier or barrier potential difference.

Ans : SQP 2023

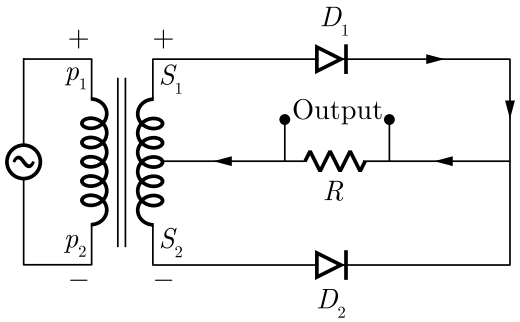
Depletion region : The small region on either side of the junction which is depleted of mobile (free) charge carriers and has only immobile ions is called depletion region.

Potential barrier : The accumulation of negative charges in p-region and positive charges in the n-region set-up a potential barrier i.e., the potential difference across the depletion region. It opposes the diffusion of electron and holes across the junction.

70. Draw a labelled circuit diagram of a full wave rectifier. Show graphically how the output voltage varies with time.

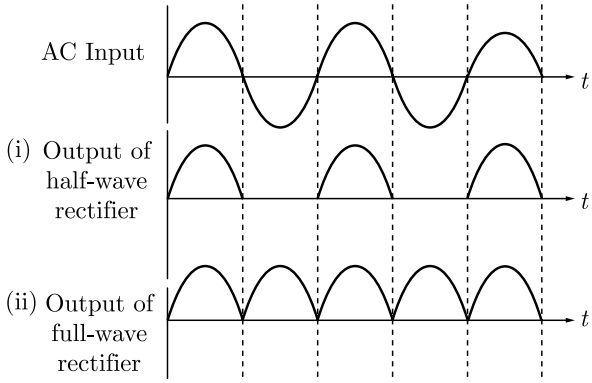
Ans : Main 2023

The labelled diagram of a full wave rectifier is given below :



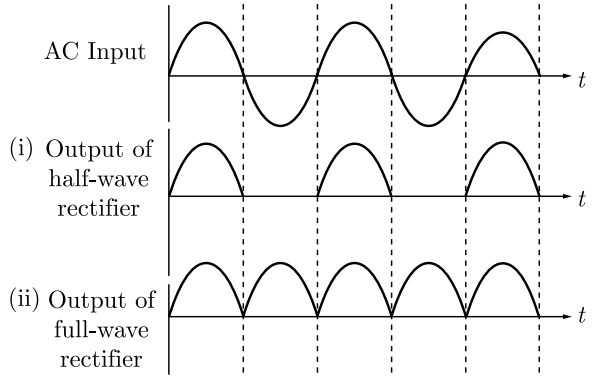
71. Draw a labelled circuit diagram of a half-wave rectifier and give its output waveform.

Ans : Main 2019



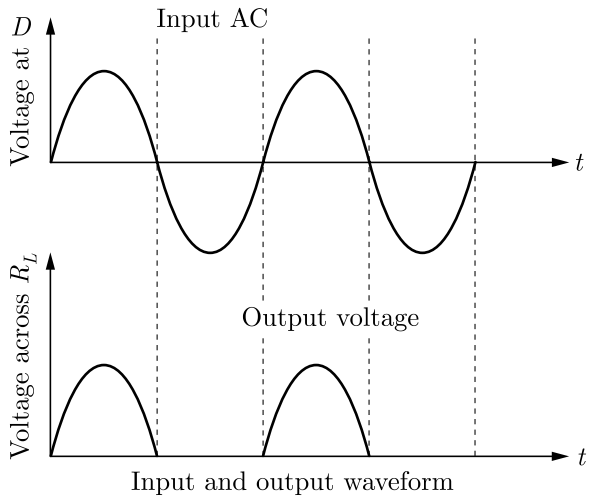
72. Draw a labelled diagram of a full wave rectifier. Show how output voltage varies with time if voltage is a sinusoidal voltage.

Ans : Main 2015



73. Show graphically, how output voltage varies with time in case of a half wave rectifier when an AC voltage is fed to it from the mains.

Ans : Main 2025, 2019

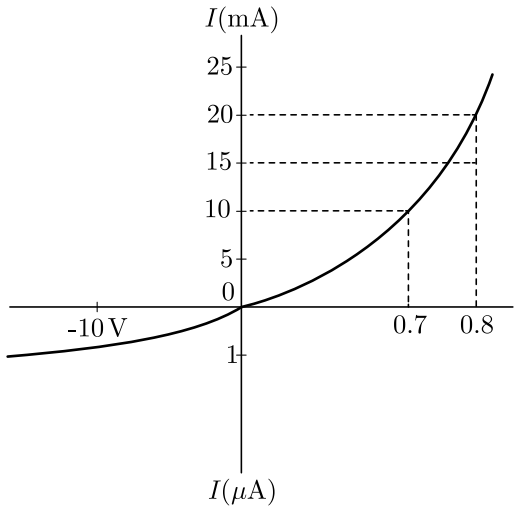


Input and output waveform

NODIA

NUMERICAL QUESTIONS

91. The characteristic curve of a silicon diode is shown below.



Calculate the resistance of the diode at

(a) $I = 15$ mA and (b) $V = -10$ Volt

Ans : SQP 2025

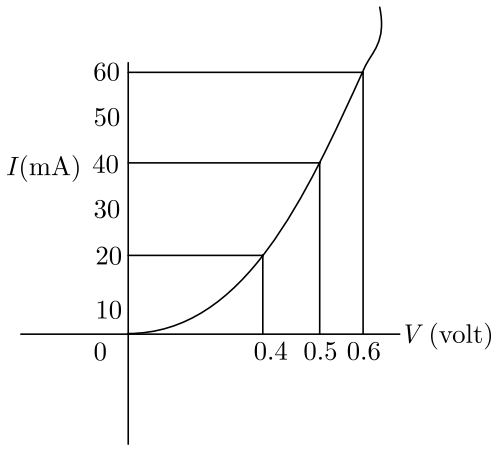
(a) From the graph, at

$$R = \frac{\Delta V}{\Delta I} = \frac{(0.8 - 0.7)}{(20 - 10) \times 10^{-3}} = 10\,\Omega$$

(b) From the graph, at

$$R = \frac{\Delta V}{\Delta I} = \frac{(-10 - 0)}{(-1 - 0) \times 10^{-6}} = 10^7\,\Omega$$

92. The forward characteristic curve of a junction diode is shown in figure below



Calculate the resistance of the diode at

I. $V = 0.5$ Volt

II. $I = 60$ mA

Ans : Main 2018

I. At $V = 0.5$ V, the current is 40 mA from the figure.

Diode resistance,

$$R_d = \frac{\Delta V}{\Delta I} = \frac{(0.5 - 0.4)}{(40 - 20) \times 10^{-3}} = 5\,\Omega$$

II. At $I = 60$ mA, the voltage is 0.6 V from the figure.

Voltage, $V = 0.6$ Volt

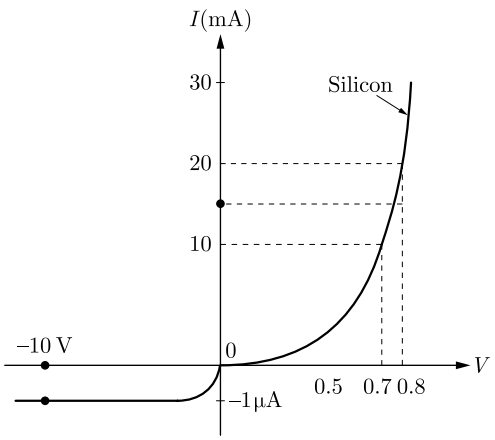
$I = 60 \times 10^{-3}$ A

Diode resistance,

$$R_d = \frac{\Delta V}{\Delta I} = \frac{(0.6 - 0.5)}{(60 - 40) \times 10^{-3}} = 5\,\Omega$$

93. The V-I characteristic of a silicon diode is as shown in the figure. Calculate the resistance of the diode at

1. $I = 15$ mA
2. $V = -10$ Volt.



Ans : Comp 2020, 2014

1. By considering straight line of $V - I$ characteristic curve between 10 mA to 20 mA and assuming passing through the origin, draw horizontal and vertical lines from 10 mA and 20 mA, we have

$$I_1 = 10\text{ mA}$$

$$V_1 = 0.7\text{ Volt}$$

$$I_2 = 20\text{ mA}$$

$$V_2 = 0.8\text{ Volt}$$

Dynamic resistance in forward biasing can be given as,

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78. Distinguish between n-type and p-type semiconductors.

Ans : **Comp 2015, 2013**

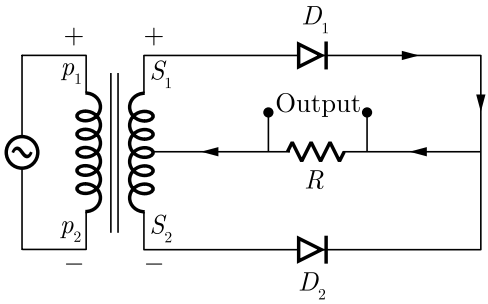
The difference between n-type and p-type semiconductor are as follows :

	n-type Semiconductor	p-type Semiconductors
1.	These are extrinsic semiconductors obtained by doping impurity atoms of group V to Ge or Si crystal.	These are extrinsic semiconductors obtained by doping impurity atoms of group III to Ge or Si crystal.
2.	The impurity atoms added provide free electrons and are called donors.	The impurity atoms added create vacancies of electrons (or holes) and are called acceptors
3.	The donor impurity level lies just below the conduction band.	The acceptor impurity level lies just above the valence band.
4.	The electrons are majority charge carriers while holes are minority charge carriers.	The holes are majority charge carriers while electrons are minority charge carriers.
5.	The free electron density is much greater than hole density i.e. $n_e >> n_h$	The hole density is much greater than free electron density i.e. $n_h >> n_e$.

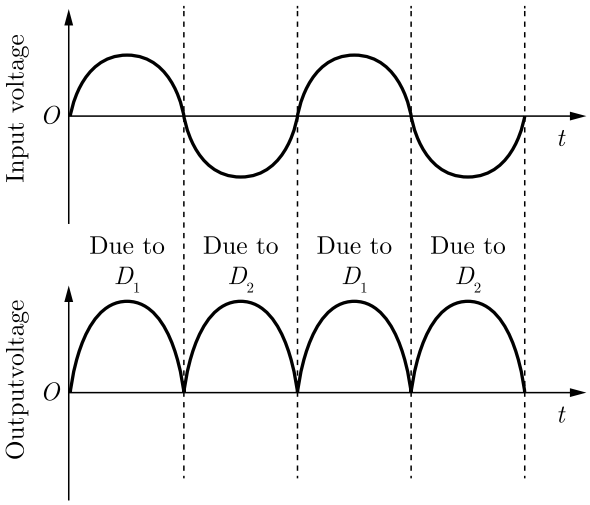
79. Draw the circuit diagram of a full-wave rectifier using $p-n$ junction diode. Explain its working and show the output input waveforms.

Ans : **Main 2011**

The circuit diagram of full-wave rectifier is shown below:



The input and output waveforms have been given below :



Its working based on the principle that junction diode offer very low resistance in forward bias and very high resistance in reverse bias.

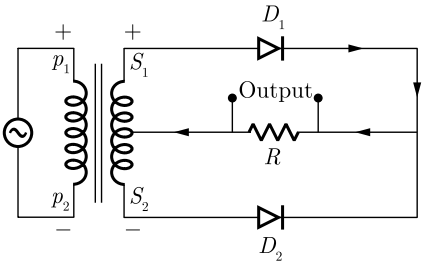
80. Answer the following questions :

(a) Draw the circuit diagram of a full wave rectifier.

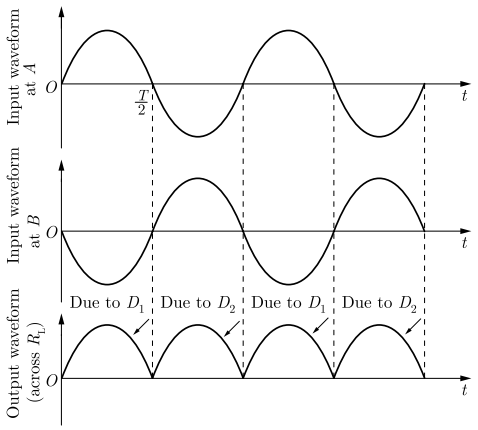
(b) Draw labelled graphs showing the input and output voltages.

Ans : **Main 2022 Sem-I**

(a)



(b)



NODIA

81. Using the necessary circuit diagrams, show how the $V-I$ characteristics of a $p-n$ junction are obtained in:

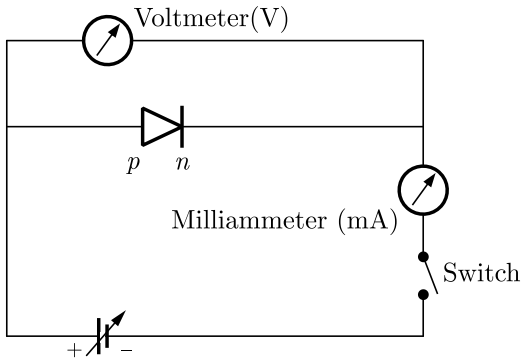
(a) Forward biasing

(b) Reverse biasing

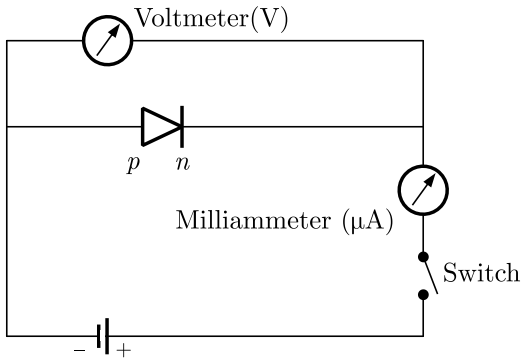
How are these characteristics made use of in rectification?

Ans : **Main 2025**

The circuit arrangement for studying the $V-I$ characteristics of a diode are shown in figure (a) and (b). For different values of voltages, the value of current is noted. A graph between V and I is obtained as in figure (c). From the $V-I$ characteristic of a junction diode, it is clear that it allows current to pass only when it is forward biased. So, if an alternative voltage is applied across a diode, the current flows only in that part of the cycle when the diode is forward biased. This property is used to rectify alternating voltages.



(a)

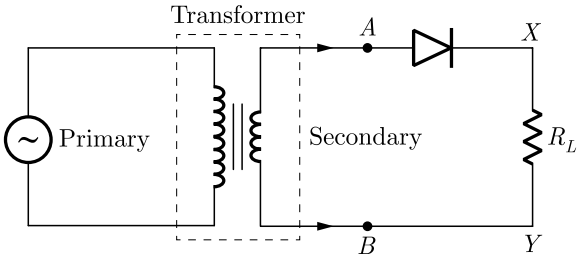


(b)

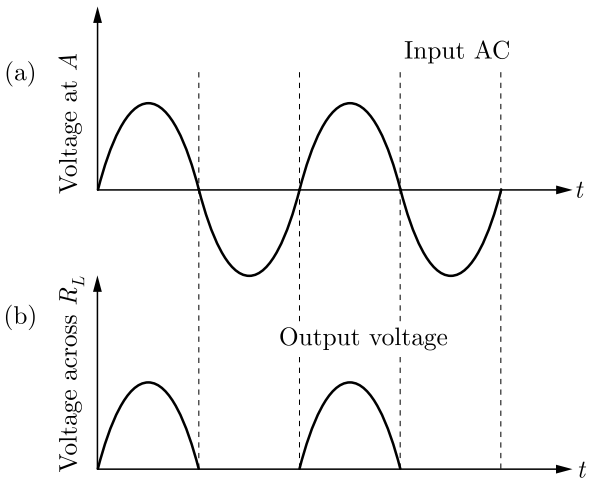
82. Explain, with the help of a circuit diagram, the working of a $p-n$ junction diode as a half-wave rectifier.

Ans : **SQP 2017, 2015**

1. $p-n$ **Junction Diode as a Half-Wave Rectifier :** AC voltage to be rectified is connected to the primary coil of a step-down transformer. Secondary coil is connected to the diode through resistors R_L, across which output is obtained.



2. **Working :** During positive half cycle of the input AC, the $p-n$ junction is forward biased. Thus, the resistance in $p-n$ junction becomes low and current flows. Hence, we get output in the load. During negative half cycle of the input AC, the $p-n$ junction is reverse biased. Thus, the resistance of $p-n$ junction is high and current does not flow. Hence, no output in the load. So, for complete cycle of AC, current flows through the load resistance in the same direction.



Input and Output Waveforms

83. Draw $V-I$ characteristics of a $p-n$ junction diode. Answer the following questions, giving reasons :

(i) Why is the current under reverse bias almost independent of the applied potential upto a critical voltage?

(ii) Why does the reverse current show a sudden increase at the critical voltage?

Name any semiconductor device which operates under the reverse bias in the breakdown region.

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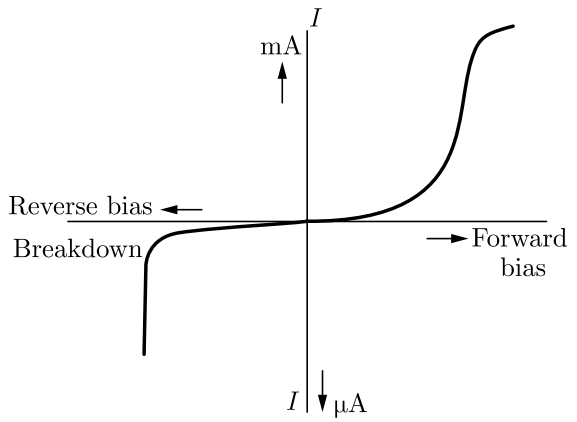
Ans : **SQP 2008**



(i) In the reverse biasing, the current of order of μA is due to movement/drifting of minority charge carriers from one region to another through the junction.

A small applied voltage is sufficient to sweep the minority charge carriers through the junction. So, reverse current is almost independent of critical voltage.

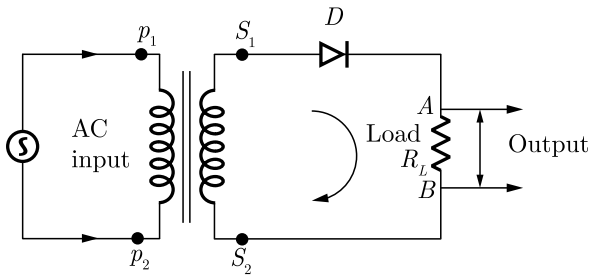
(ii) At critical voltage (or breakdown voltage), a large number of covalent bonds break, resulting in the increase of large number of charge carriers. Hence, current increases at critical voltage.

Semiconductor device that is used in reverse biasing, is zener diode.

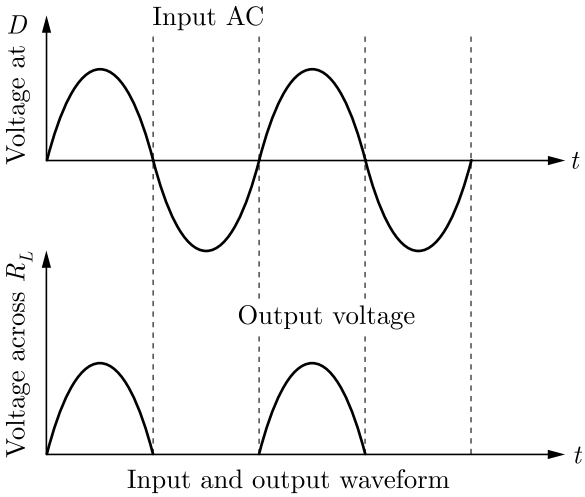
84. Draw the circuit diagram of a half-wave rectifier using a semiconductor diode. Explain briefly the functions of each component.

Ans : **Main 2000**

The diagram below shows a semiconductor diode used as a half-wave rectifier.



The figure shows an AC input voltage is applied across the primary coil P_1P_2 of transformer and S_1S_2 is the secondary coil of the same transformer. During first half cycle, the end S_1 of the transformer is positive with respect to the end S_2. The diode is then in forward bias condition hence, current flows through it. In the load R_L, the current flows from A to B. During second half cycle, S_1 is negative with respect to S_2, then the diode is said to be in reverse biased and is non-conducting. Hence, current through load R_L is zero.Thus, the output current flows in one direction only. The lower half part of the AC is cut-off, only the upper half part constitutes current. Thus, a semiconductor diode acts as a half-wave rectifier. The wave diagram is shown as below.



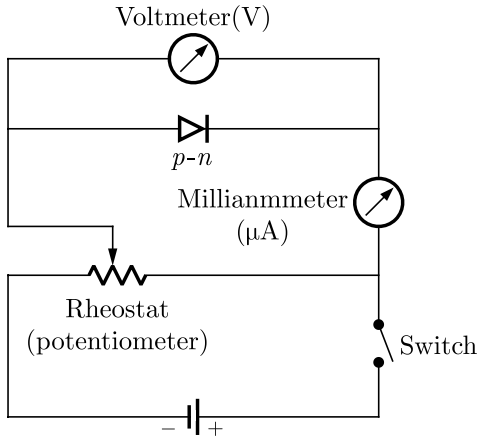
Input and output waveform

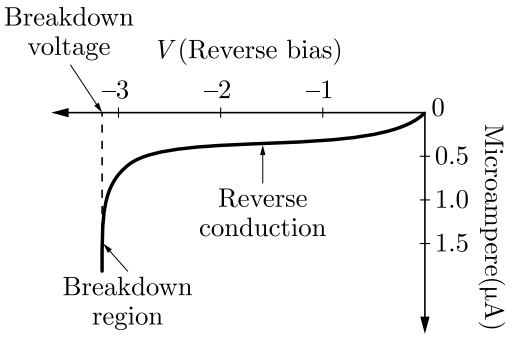
NODIA

85. What is meant by reverse biasing of a semiconductor diode? Draw a labelled characteristic curve, i.e I-V graph for a semiconductor diode during reverse bias.

Ans : **Main 2023**

A junction diode is said to be reverse biased, when the positive terminal of the external battery is connected to the n-side and negative terminal to the p-side of the diode. As, the direction of applied voltage is in same direction of built in potential or barrier potential of, therefore width of depletion layer increases and hence, it offers high resistance.





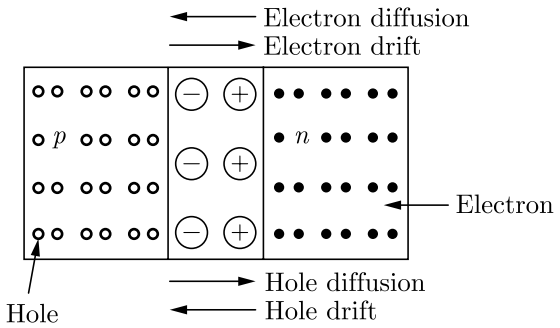
86. Describe briefly, with the help of a diagram, the role of the two important process involved in the formation of a $p-n$ junction.

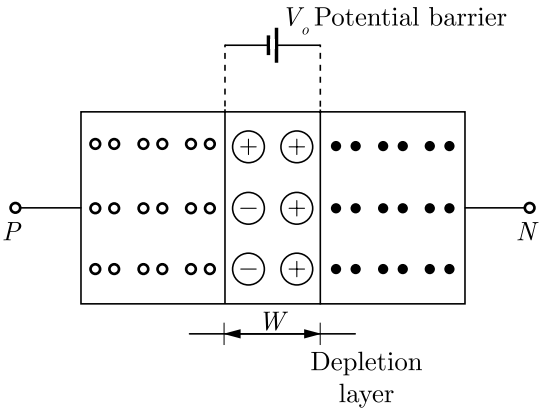
Ans : **Main 2012**

Two important processes occurring during the formation of a $p-n$ junction are

(i) **Diffusion :** In n-type semiconductor, the concentration of electrons is much greater as compared to concentration holes ; while in p-type semiconductor, the concentration of holes is much greater than the concentration of electrons. When a $p-n$ junction is formed, then due to concentration gradient, the holes diffuse from p-side to n-side $(p \rightarrow n)$ and electrons diffuse from n-side to p-side $(n \rightarrow p)$. This motion of charge carriers gives rise to diffusion current across the junction.

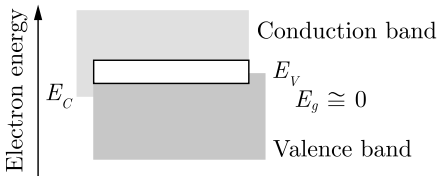
(ii) **Drift :** The drift of charge carriers occurs due to electric field. Due to built in potential barrier, an electric field directed from n-region to p -region is developed across the junction. This field causes motion of electrons on p-side of the junction to n-side of junction to p-side. Thus, a drift current starts. This current is opposite to the direction of diffusion current.

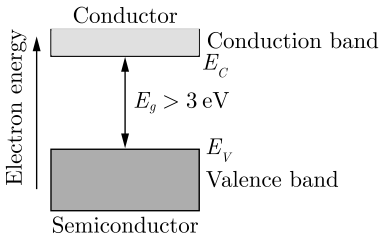


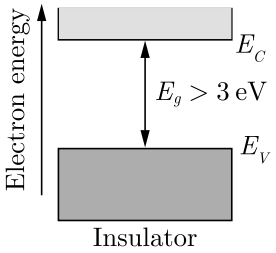


87. Draw the necessary energy band diagrams to distinguish between conductors, semiconductors and insulators. How does the change in temperature affect the behaviour of these materials? Explain briefly.

Ans : **Comp 2014, 2011**







Distinguishing Features :

(a) **In conductors :** Valence band and conduction band overlap each other.

In semiconductors Valence band and conduction band are separated by a small energy gap.

In insulators : They are separated by a large energy gap.

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(b) **In conductors :** Large number of free electrons are available in conduction band.

In semiconductors A very small number of electrons are available for electrical conduction.

In insulators Conduction band is almost empty i.e., no electron is available for conduction.

Effect of temperature :

(a) **In conductors :** At high temperature, the collision of electrons become more frequent with the atoms/molecules at lattice site in the metals as a result the conductivity decreases (or resistivity increases).

(b) **In semiconductors :** As the temperature of the semiconducting material increases, more electron hole pairs becomes available in the conduction band and valence band and hence the conductivity increases or the resistivity decreases.

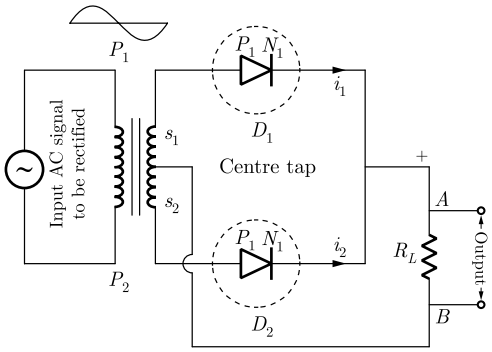
(c) **In insulators :** The energy band between conduction band and valence band is very large, so it is un-surpassable for small temperature rise. So, there is no change in their behaviour.

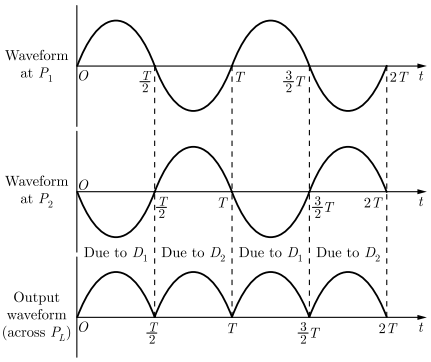
FOUR MARKS QUESTIONS

88. State the principle of working of $p-n$ diode as a rectifier. Explain with the help of a circuit diagram, the use of $p-n$ diode as a full wave rectifier. Draw a sketch of the input and output waveforms.

Ans : **Main 2016**

Rectification means conversion of AC into DC. A p-n diode acts as a rectifier because an AC changes polarity periodically and a p-n diode allows the current to pass only when it is forward biased. This makes the diode suitable for rectification.





Working

The AC input voltage across secondary s_1 and s_2 changes polarity after each half cycle. Suppose during the first half cycle of input AC signal, the terminal s_1 is positive relative to centre tap O and s_2 is negative relative to O. Then diode D_1 is forward biased and diode D_2 is revere biased. Therefore, diode D_1 conducts while diode D_2 does not. The direction of current (i_1) due to diode D_1 in load resistance R_L is direction from A to B. In next half cycle, the terminal s_1 is negative and s_2 is positive relative to centre tap O. The diode D_1 is reverse biased and diode D_2 is forward biased. Therefore, diode D_2 conducts while D_1 does not. The direction of current (i_2) due to diode D_2 in load resistance R_L is still from A to B. Thus, the current in load resistance R_L is in the same direction for both half cycles of input AC voltage. Thus for input AC signal the output current is a continuous series of unidirectional pulses.

In a full wave rectifier, if input frequency is f hertz, then output frequency, will be $2f$ hertz because for each cycle of input, two positive half cycles of output are obtained.

89. What is rectifier ? How a p-n junction diode can be used in (1) forward biased and (2) reverse biased mode ? Draw a labelled V-I characteristic of $p-n$ junction diode on a graph.

Ans : **Main 2016**

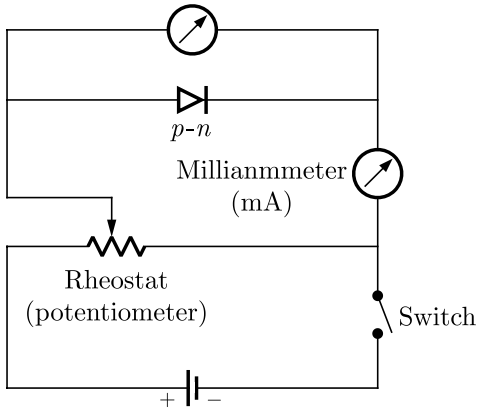
The process of converting alternating current into direct current is called rectification and the device used for this process is called rectifier.

V-I Characteristics of a p-n Junction Diode

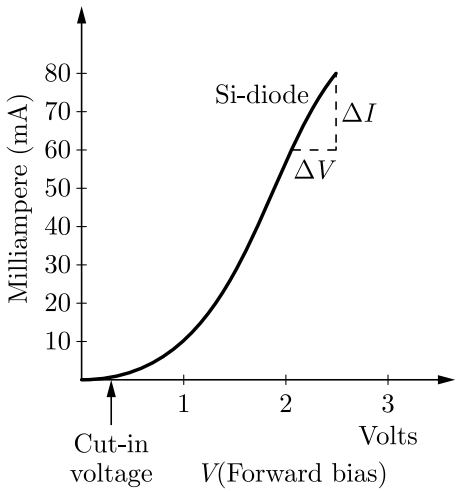
A graph showing the variation of current flowing through a p-n junction with the voltage applied across it (both when it is forward and reverse biased) is called the voltage-current or V-I characteristic of p-n junction.

NODIA

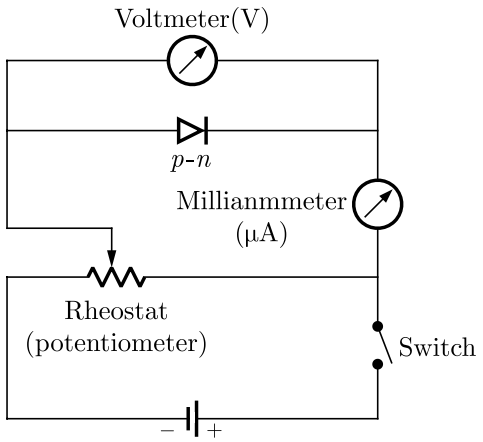
1. **Forward Bias Characteristic :** Figure shows the experimental arrangement for studying the characteristic curve of a p-n junction when it is forward biased.



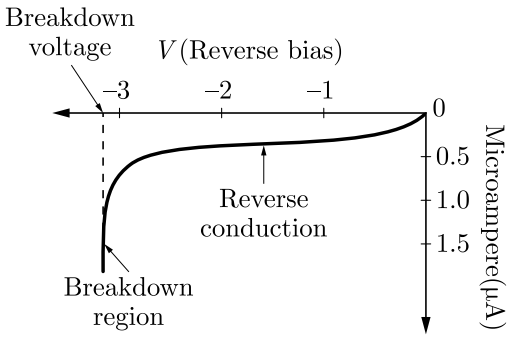
A battery is connected across the p-n junction diode through a potentiometer (or rheostat) so that the voltage applied to the diode can be changed. The milliammeter measures the current through the diode and the voltmeter measures the voltage across the diode. For different values of voltages, the value of current is noted. A graph is plotted between V and I, as shown in Figure. This voltage-current graph is called forward characteristics.



2. **Reverse Bias Characteristic :** Figure shows the experimental arrangement for studying characteristic curve of a p-n junction when it is reverse biased.



Here a micro-ammeter is used to measure the small currents through the reverse biased diode. A V-I graph of the type shown in Figure. It is called reverse characteristic of the junction diode.



90. Explain the band theory of solids. State how on this basis solids are classified into conductors, insulators and semiconductors.

Ans : **Main 2017, 2013**

From Bohr's atomic model, we know that the electrons have well defined energy levels in an isolated atom. But due to interatomic interactions in a crystal, the electrons of the outer shells are forced to have energies different from those in isolated atoms. Each energy level splits into a number of energy levels forming a continuous band, called energy band.

Depending on the energy band gap is zero, large or small, the solids may be classified into metals, insulators and semiconductors, as explained below:

1. **Metals :** Here the last occupied band, called conduction band is partially filled with electrons. Two types of band structures are found in metals:
   (a) Either there is energy gap between the completely filled valence band and the

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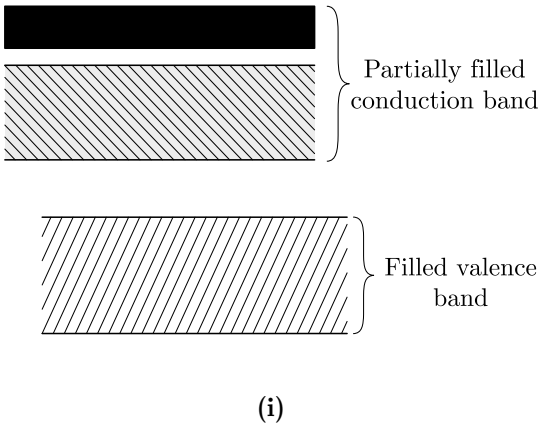
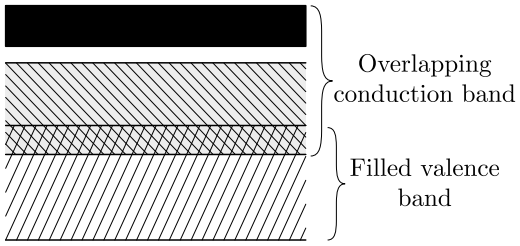
partially filled conduction band. As shown in figure (i), this band structure is met in alkali metals (Li, Na, K, etc.), noble metals (Cu, Ag, Au) and third group elements like Al, Ga, In and Tl.



(i)

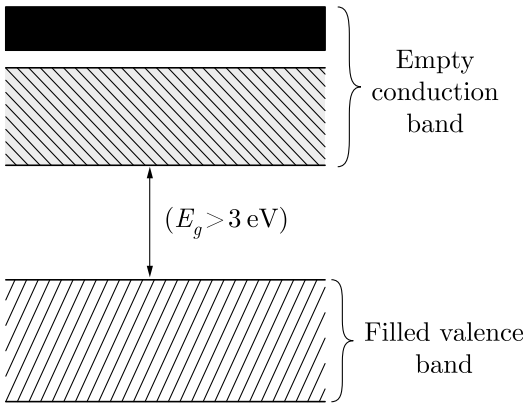


(ii)

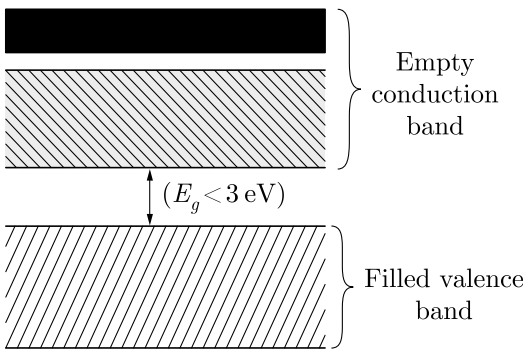
(b) The conduction and valence band partly overlap. As shown in figure(ii), this band structure is seen in metals like Be ($Z = 4: 1s^2 2s^2$), Mg ($Z = 12: 1s^2 2s^2 2p^6 3s^2$), Zn etc. Here the valence band is completely filled but the upper unoccupied band ($2p$ with $2s$ in Be, $3p$ with $3s$ in Mg) partly overlaps the valence band.

The highest energy level in the conduction band filled up with electrons at absolute zero is called fermi level and the energy corresponding to the fermi level is called fermi energy. Many electrons after gaining a slight amount of energy from any source get excited to the empty energy levels lying immediately above the fermi level and become free to conduct electricity. This makes available a large number of conduction electrons. So metals have low resistivity or high conductivity. Even a small electric field applied across the metal causes a current flow through it.

2. **Insulators :** In insulators, the valence band is completely filled while the conduction band is empty as shown in Figure (b), there is a larger energy gap ($E_g > 3$ eV) between the valence and conduction bands. For example, in case of diamond, $E_g = 6$ eV. Even an electric field cannot give this much energy to an electron to make it jump from the valence band into the conduction band. Hence due to the lack of free electrons in the conduction band, the insulators are poor conductors of electricity.



3. **Semiconductors :** At $0K$, the conduction band is empty and the valence band is filled. So the material is essentially insulator at low temperatures. However, the energy gap between conduction and valence bands is small ($E_g < 3$ eV). For example, $E_g = 1.17$ eV for Si and $E_g = 0.74$ eV for Ge. At room temperature, some valence electrons acquire enough thermal energy and jump to the conduction band where they are free to conduct electricity (according to Boltzmann law, number of thermally excited electrons $n \propto e^{-Eg/kT}$) Thus the semiconductor acquires a small conductivity at room temperature. The resistance of a semiconductor would not be as high as that of insulator.



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14. With reference to semiconductor physics,

(a) Name the diode that emits spontaneous radiation when forward biased.

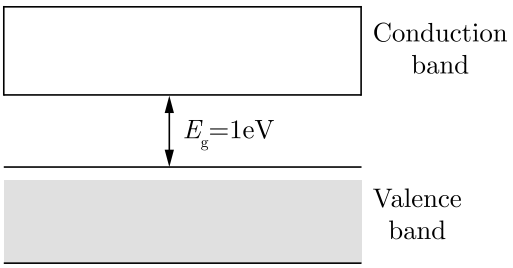
(b) Draw a labelled energy band diagram for a semiconductor.

(c) Name the process that causes depletion region in a p-n junction.

Ans : **SQP 2014**

(a) Light Emitting Diode (LED) emits spontaneous radiation when forward biased.

(b)

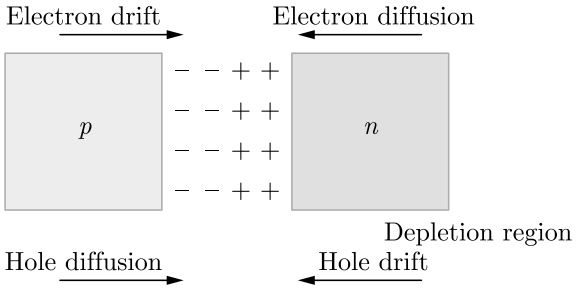


(c) The depletion layer of a p-n junction diode is due to doping of the materials and diffusion of charge carriers.

15. State briefly the process involved in the formation of $p-n$ junction explaining clearly how the depletion region is formed.

Ans : **SQP 2018, 2011**

Two processes occur during the formation of a $p-n$ junction are diffusion and drift. Due to the concentration gradient across p and n-sides of the junction, holes diffuse from p-side to n-side ($p \rightarrow n$) and electrons diffuse from n-sides to p -side ($n \rightarrow p$). This movement of charge carriers leaves behind ionised acceptors (negative charge ϕ-immobile) on the p-side and donors (positive charge immobile) on the n-side of the junction. This space charge region on either side of the junction together is known as depletion region.

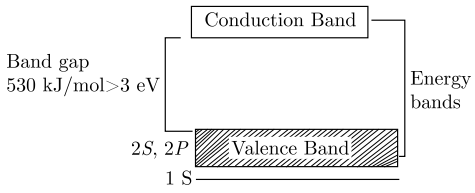


16. Draw a labelled energy band diagram for a solid which is an insulator. What is the main difference between this diagram and that of a semiconductor?

Ans : **Main 2011**

In solids, there are two types of energy bands naming conduction band and valence band. Conduction band is of higher energy and hence, less stable.

Energy band diagram for an insulator is shown below. Energy bands of diamond $(1s^2, 2s^2, 2p^2)$.



Difference between energy band diagram of insulator and semiconductor :

Energy gap between valence band and conduction band is approximately equal to 530 kJ/mol(> 3 eV) (very large) in insulators which is much higher than that for a semiconductor. So on giving temperature, electrons can jump from valence band to conduction band and increases its conductivity in case of semiconductors.

17. With reference to a semiconductor diode, define the terms 'depletion region' and 'potential barrier'. How will the width of depletion region change during reverse biasing?

Ans : **SQP 2018**

Depletion region : The small region on either side of the junction which is depleted of mobile (free) charge carriers and has only immobile ions is called depletion region.

Potential barrier : The accumulation of negative charges in p-region and positive charges in the n-region set-up a potential barrier i.e., the potential difference across the depletion region. It opposes the diffusion of electron and holes across the junction.

Effect on depletion region during reverse biasing

During reverse biasing, the positive terminal of the external battery attracts electrons from n-region and its negative terminal attracts holes from p-region.

Due to which, holes in the p-region and electrons in the n-region are pushed away from the function. Hence, potential barrier and with of the depletion layer increases.

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$$R = \frac{\Delta V}{\Delta I} = \frac{V_2 - V_1}{I_2 - I_1}$$
$$= \frac{(0.8 - 0.7)\,\text{V}}{(20 - 10)\,\text{mA}}$$
$$= \frac{0.1\,\text{V}}{10\,\text{mA}}$$
$$= \frac{0.1}{10} \times 10^3\,\Omega$$
$$= 10\,\Omega$$

2. At -10 V. The V-I characteristic graph is a straight line parallel to the voltage axis and not showing any variation. So, the static resistance can be given as,

$$V = -10\ \text{Volt}$$

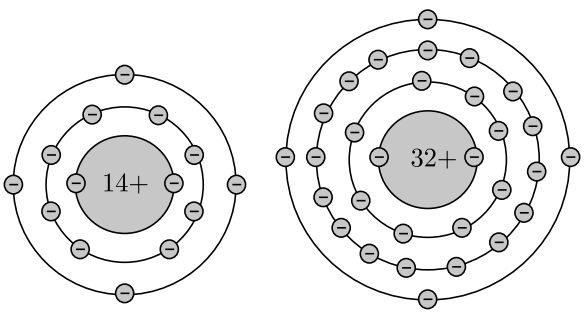
and $$I = -1\,\mu\text{A}$$

Hence, Static resistance,

$$R = \frac{V}{I} = \frac{10\,\text{V}}{1\,\mu\text{A}}$$
$$= \frac{10}{1 \times 10^{-6}}$$
$$= 10^7\,\Omega$$

CASE BASED QUESTIONS

94. Anita was thinking that C, Si and Ge have same lattice structure, but C is insulator while Si and Ge intrinsic semiconductors. For its answer, she meet her friend Parul. Parul explained him that the four bonding electrons of C, Si and Ge lie respectively in the second, third and fourth orbit. So, energy required to take out an electron from these atoms known as ionisation energy I_E will be least for Ge, followed by Si and highest for C. Hence number of free electrons for conduction in Ge and Si are significant while negligible small for C.



A B

(a) Which is better silicon or germanium?

(b) If a pure silicon crystal has 5×10^{28} atoms/m^3. It is doped by 1 ppm concentration of pentavalent arsenic.
If $n_i = 1.5 \times 10^{16}$/m^3, then calculate the number of electrons and holes.

Ans :

(a) In present, Silicon is preferred over Germanium for semiconductor. Silicon can be worked at a higher temperature as compared to germanium. The structure of Germanium crystals will be destroyed at higher temperature. Also, Silicon has much smaller leakage current than that of germanium.

(b) Given, $n_i = 1.5 \times 10^{16}$/m^3
$n = 5 \times 10^{28}$atoms/m^3

The number of free electrons n_e in the doped silicon is given by

$$n_e = \frac{1}{10^6} \times n = \frac{5 \times 10^{28}}{10^6}$$
$$= 5 \times 10^{22}/\text{m}^3$$

Now, in a doped semiconductor,

$$n_e n_h = n_i^2$$
$$n_h = \frac{n_i^2}{n_e} = \frac{(1.5 \times 10^{16})^2}{5 \times 10^{22}}$$
$$= \frac{2.25 \times 10^{32}}{5 \times 10^{22}}$$
$$= 4.5 \times 10^9/\text{m}^3$$

95. Certain materials have the basic crystal structure of an insulator but with a much smaller energy gap (of the order of an electron-volt) between the valence band and the conduction band. Such solids are known as 'semiconductors'. Silicon and germanium having energy gaps of 1.1 eV and 0.7 eV respectively are typical examples of semiconductors.

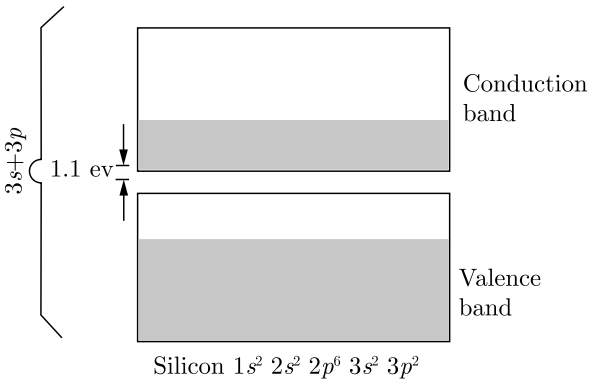


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Figure shows the energy bands of silicon. At room temperature, a few of its electrons in the valence band have sufficient kinetic energy of thermal motion to cross the narrow energy gap and enter the conduction band above it. Hence, when an electric field is applied, the few electrons present in the conduction band acquire additional energy to move to the unoccupied levels within the same band. similarly, a few of the many electrons present in the valence band move to the few available unoccupied levels in the same band. Hence, there is a limited flow of current across the crystal. Thus, silicon has an electrical conductivity intermediate between those of conductors and insulators and it therefore a semiconductor.

(i) What do you mean by semiconductor?

(ii) Name the elements having the energy gaps of 1.1 eV and 0.7 eV, respectively.

(iii) When the electrons are jumped from valence band to conduction band?

(iv) In which types of materials the free electrons are not able to jump from valence band to conduction band?

(v) Draw a diagram of valence band as well as the conduction band and their energy gap.

Ans :

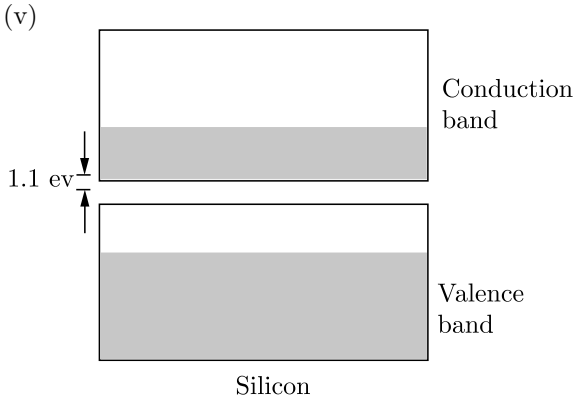
(i) A semiconductor is a substance that has specific electrical properties that enable it to serve as a foundation for computers and other electronics devices.

(ii) Silicon and germanium having energy gaps of 1.1 eV and 0.7 eV, respectively.

(iii) The electrons which are in valence band have the enough energy to jump to the conduction band.

(iv) Insulators are the materials that have no free electrons to jump from valence band to conduction band.

(v)



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